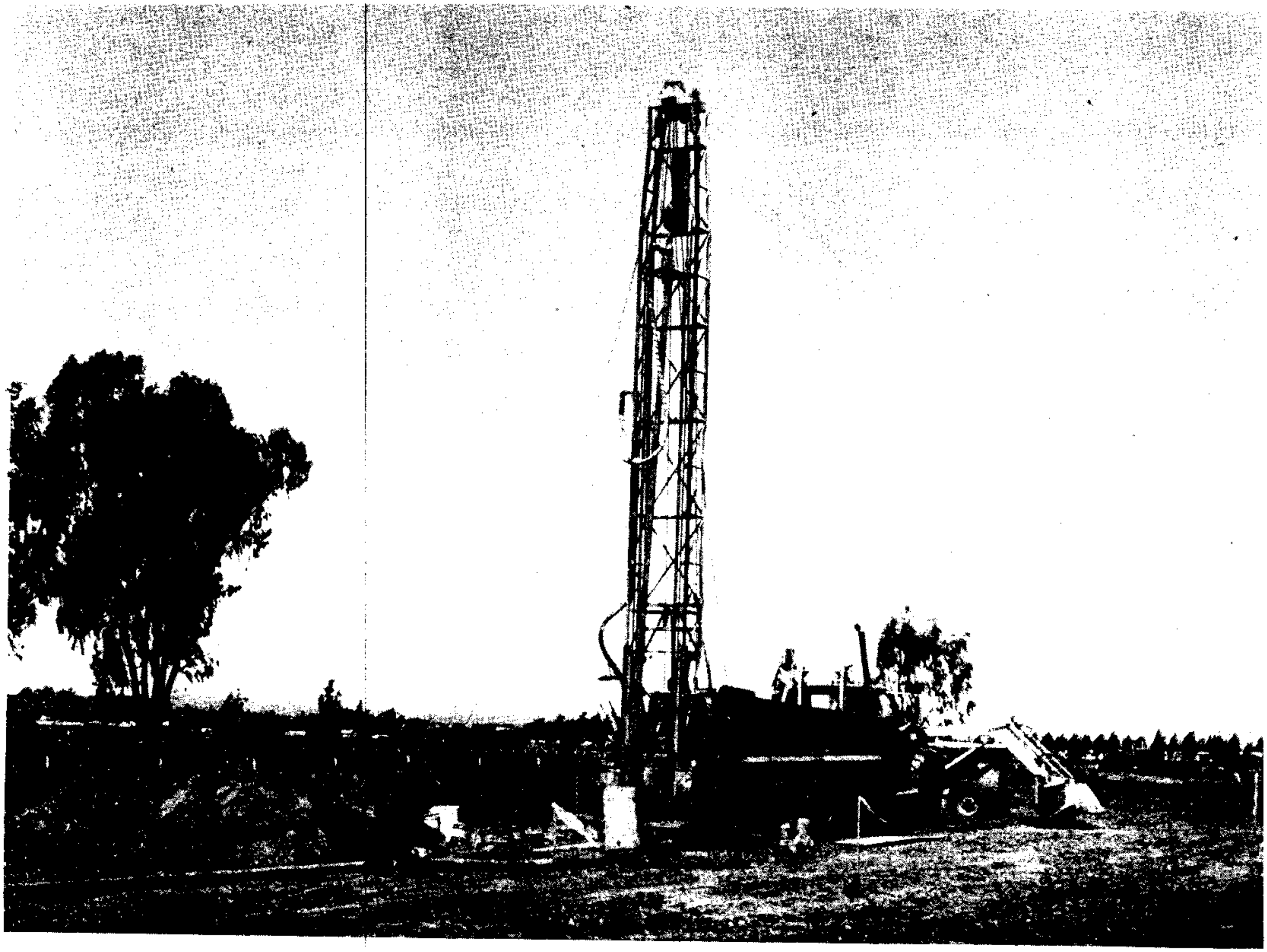

State of California
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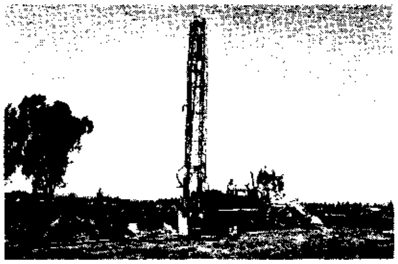
Evaluation of Ground Water Resources Sonoma County Volume 2: Santa Rosa Plain

Department of Water Resources
in cooperation with the Sonoma County Water Agency

Bulletin 118-4
September 1982



ON THE COVER: In May 1980, the drilling rig drilled a test hole prior to the construction of Cotati Municipal Water Well #3 on Santa Rosa Plain. Data from the test hole were used to design the well so that the maximum yield of ground water could be assured. The City of Cotati and its neighbor Rohnert Park use ground water to meet most of their municipal water demands.

Department of Water Resources
in cooperation with the
Sonoma County Water Agency

Bulletin 118-4

Evaluation of Ground Water Resources: Sonoma County

Volume 2 Santa Rosa Plain

September 1982

Huey D. Johnson
Secretary for Resources

The Resources Agency

Edmund G. Brown Jr.
Governor

State of California

Ronald B. Robie
Director

Department of Water Resources

FOREWORD

Ground water plays an important role in Sonoma County. As the population of this North Bay county has increased over the last 30 years, the use of ground water has likewise increased. Currently, over 15,000 wells have been identified in the county. These wells are used for domestic and agricultural purposes in rural areas and for municipal and industrial purposes in urban areas.

The Sonoma County Water Agency (SCWA) requested the California Department of Water Resources (DWR) to undertake a cooperative study to estimate the volume of ground water in storage and the recharge potential in the Santa Rosa Plain, Petaluma Valley, Sonoma Valley, and Alexander Valley and Healdsburg area. The study examined alternative ways the ground water resources of the county may be used conjunctively with the Russian River and other surface water sources.

The present study was designed to augment the earlier countywide investigation of geology and hydrology conducted jointly by the Sonoma County Planning Department and DWR. Results of the earlier investigation were published as DWR Bulletin 118-4, Volume 1 (Ford, 1975). The results of this study are presented in four volumes. This report is Volume 2 and describes ground water conditions in the Santa Rosa Plain. Volume 3 deals with the Petaluma Valley, Volume 4 with the Sonoma Valley, and Volume 5 with the Alexander Valley and Healdsburg area.

This report on the Santa Rosa Plain includes an evaluation of geologic and hydrologic characteristics of the ground water basin, an evaluation of the volume of fresh ground water in the basin, possible changes in water quality resulting from pumping of ground water, an evaluation of the interconnection of ground and surface water, and the potential for artificial recharge of the ground water basin. This report also includes a description of a mathematical model of the Santa Rosa Plain developed as part of this investigation.

Ronald B. Robie, Director
Department of Water Resources
The Resources Agency
State of California

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(in separate pocket)

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CONVERSION FACTORS

	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0.3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0.26417	3.7854
	megalitres	million gallons (10^6 gal)	0.26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0.26417	3.7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 × °C)+32	(°F−32)/1.8

CHAPTER 1. INTRODUCTION

The Santa Rosa Plain (Figures 1 and 2) has the largest and fastest growing population in Sonoma County. As the population has increased, so has the demand for water. Ground water, i.e., water stored underground in the spaces between grains of sand and gravel and in cracks in consolidated rocks, plays an important role in meeting this demand.

The first and third largest cities in Sonoma County, Santa Rosa and Rohnert Park, are both located in the Santa Rosa Plain; their 1980 populations were 78,300 and 22,500, respectively. The three fastest growing cities in the county are in the Santa Rosa Plain: Rohnert Park, up 267 percent in 1980 from its 1970 population of 6,133; Cotati (2,830), up 107 percent from its 1970 population of 1,368; and Santa Rosa, up 57 percent from its 1970 population of 50,006. Of these three cities, Rohnert Park and Cotati rely principally on ground water to meet their water needs. Rapid population growth and resulting increased use of the ground water resource make a detailed evaluation of that resource important.

The Santa Rosa Plain was numbered 2-18 in California Department of Water Resources (DWR) Bulletin 118 (California Department of Water Resources, 1975). The Santa Rosa Plain is now included with other contiguous ground water reservoirs in the county in the Sonoma County Basin (Peters, 1980).*

Location of Study Area

The area of investigation comprises 47 150 hectares (116,500 acres)** extending from Windsor south to Penngrove and Bodega Avenue (Figure 2). The area includes the Atascadero Creek drainage to the west and extends to the base of the Sonoma Mountains to the east. It also includes Rincon Valley and the northern half of Bennett Valley, east of Santa Rosa.

Method of Investigation

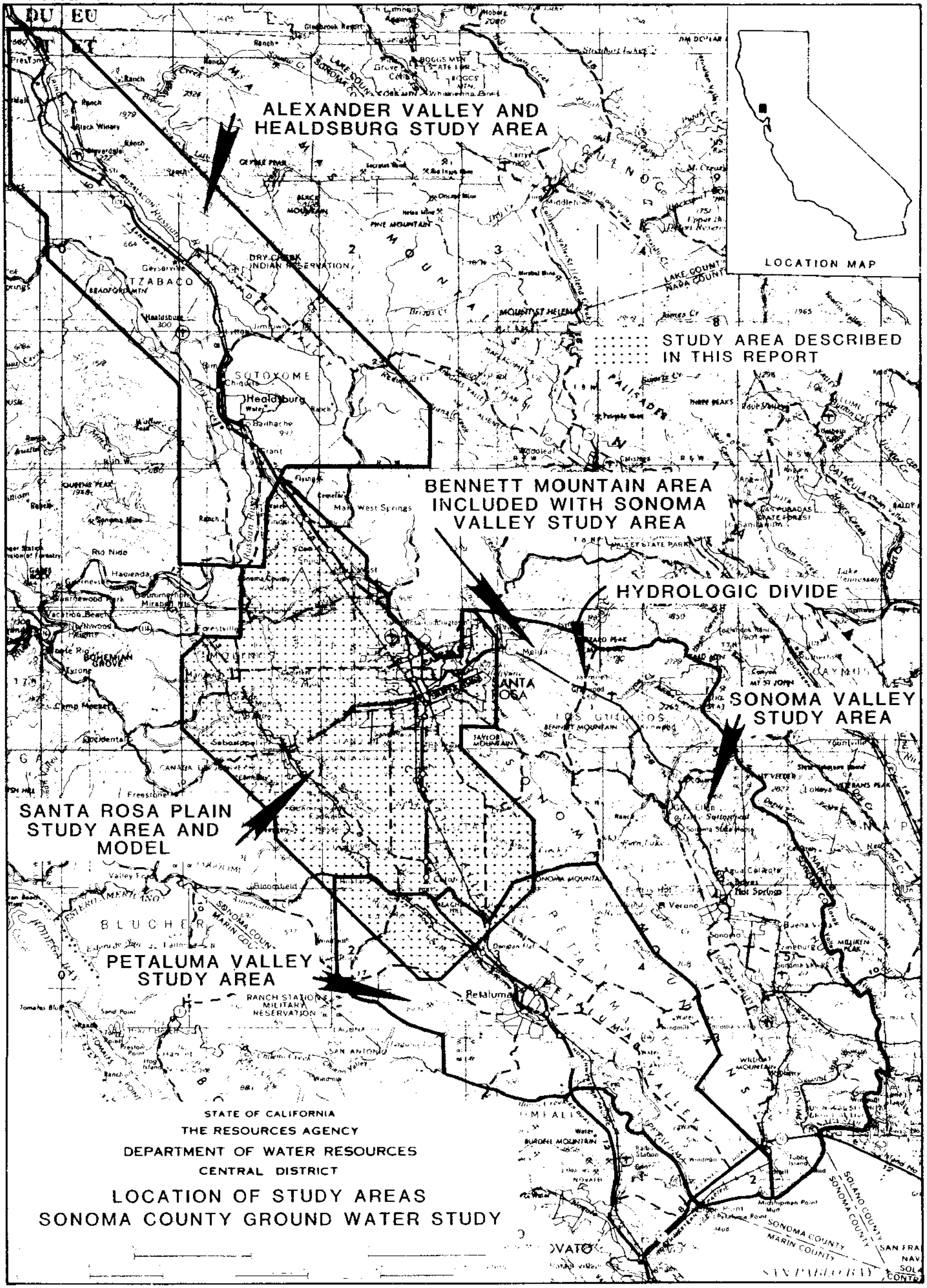
For systematic compilation and evaluation of hydrologic data for analysis, the study area has been subdivided along township, range, and section lines to form 193 cells of 130 or 260 hectares (320 or 640 acres) each. All hydrologic data, such as ground water levels, have been evaluated using these cell divisions.

Basic data available for the Santa Rosa Plain were compiled and evaluated in several different ways. Water well logs were used to develop geologic cross sections showing the subsurface geology. The well log information on types of materials encountered in each well was coded as equivalent specific yield in the TRANSCAP computer program. The log-related information was compiled by cells and the total ground water storage capacity for each cell was estimated. When combined with fall 1980 water level information, the total volume of ground water in storage and the total storage space available to receive recharge were determined. The computer program TRANSCAP assumes that all ground water in the study area is unconfined. The TRANSCAP program is discussed in more detail in Chapter 4.

* A list of references is presented following Chapter 9.

**Conversion factors for changing from metric to customary units are listed on the preceding page.

FIGURE 1



ALEXANDER VALLEY AND HEALDSBURG STUDY AREA
LOCATION MAP
STUDY AREA DESCRIBED IN THIS REPORT
BENNETT MOUNTAIN AREA INCLUDED WITH SONOMA VALLEY STUDY AREA
HYDROLOGIC DIVIDE
SONOMA VALLEY STUDY AREA
SANTA ROSA PLAIN STUDY AREA AND MODEL
PETALUMA VALLEY STUDY AREA
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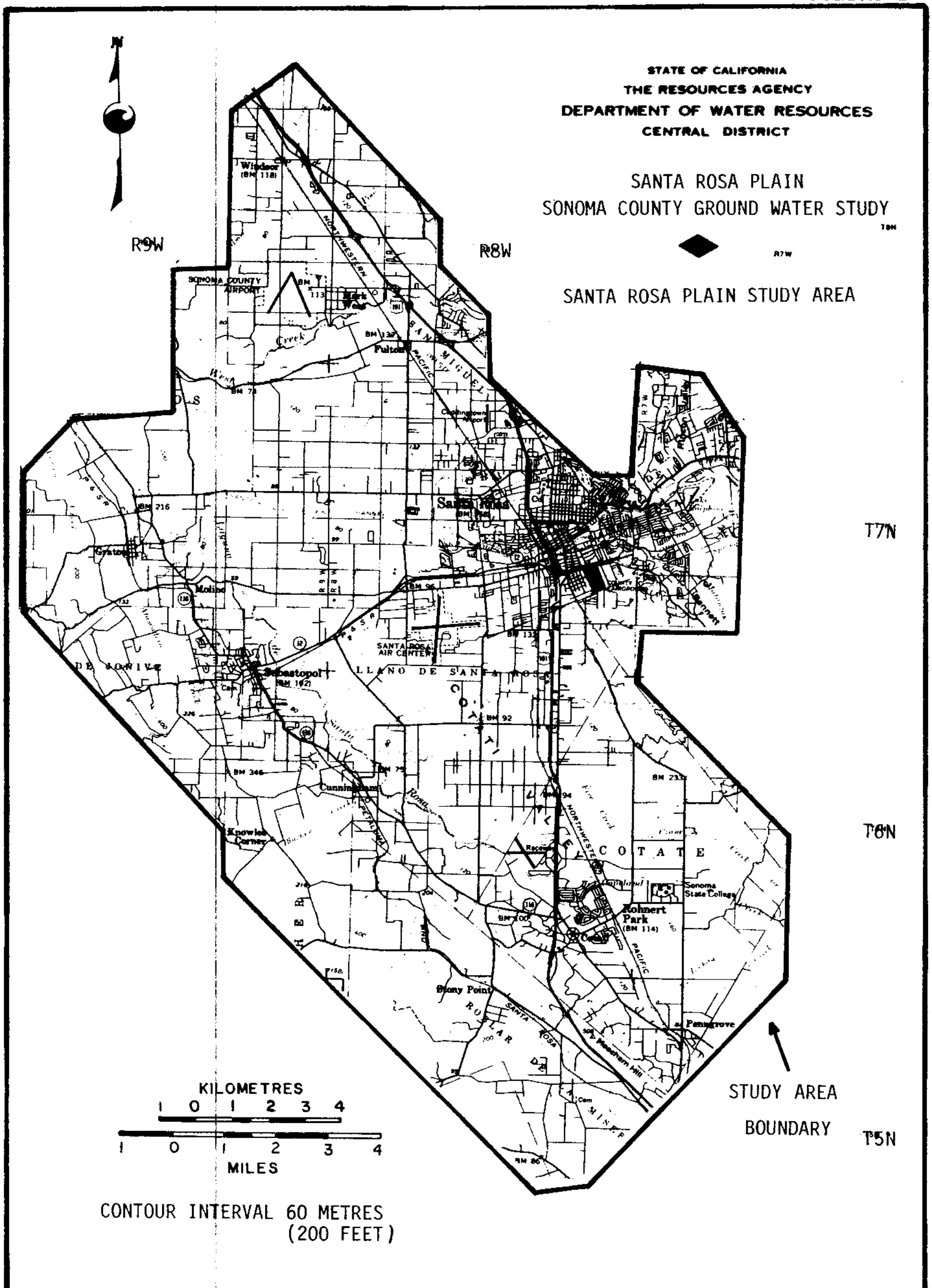
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
LOCATION OF STUDY AREAS
SONOMA COUNTY GROUND WATER STUDY

FIGURE 2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CENTRAL DISTRICT
SANTA ROSA PLAIN
SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN STUDY AREA
R9W
R8W
T7N
T6N
T5N
Windsor
SONOMA COUNTY AIRPORT
Fulton
Santa Rosa
Graton
Molino
Sebastopol
SANTA ROSA AIR CENTER
LLANO DE SANTA ROSA
Cunningham
Knowles Corner
COTATE
Sonoma State College
Rohnert Park
Cotati
Stony Point
Penngrove
NORTHWESTERN PACIFIC
STUDY AREA BOUNDARY
KILOMETRES
1 0 1 2 3 4
1 0 1 2 3 4
MILES
CONTOUR INTERVAL 60 METRES
(200 FEET)

Water level maps were compiled for the fall and spring of each year of the study period (water years 1961-1975). These maps were used to calculate the change in the amount of ground water in storage during this time. A "change in storage" map was drawn from the beginning to ending springs of the study period. The contours of this map were planimetered to calculate change in storage.

All municipal and mutual water companies in the basin were contacted and the total amount of their ground water pumpage was estimated. The number and types of private wells were tabulated, and the total pumpage from this source was also calculated. All available streamflow records were examined to determine total inflow and outflow to the basin. Where no records were available, yearly runoff was calculated by correlating the stream drainage basin to an adjacent gaged basin. Outflow for the Laguna de Santa Rosa and Mark West Creek was calculated based on the change in Russian River streamflow above and below their inflow point. Precipitation and evaporation data were also reviewed. Land-use maps were examined to determine the area per crop per cell, in order to estimate the amount of water applied for agriculture that might infiltrate to the ground water body.

The above data were then evaluated to determine a basin water balance, which is an accounting of the amount of ground water moving into and out of the basin. Data from the basin water balance were then combined with estimates of the total ground water storage capacity for each cell to develop a mathematical model of the Santa Rosa Plain. This model, when verified, can predict the effect on the entire basin of extraction or recharge in any area within it. The model is discussed in more detail in Chapters 4 and 7.

All available water quality data were tabulated and plotted on topographic maps. This information was evaluated to determine regional water quality types as an indicator of aquifer continuity. Special water quality problems, such as high sodium and salinity, were evaluated to determine areal extent, source, and potential for migration of the affected water.

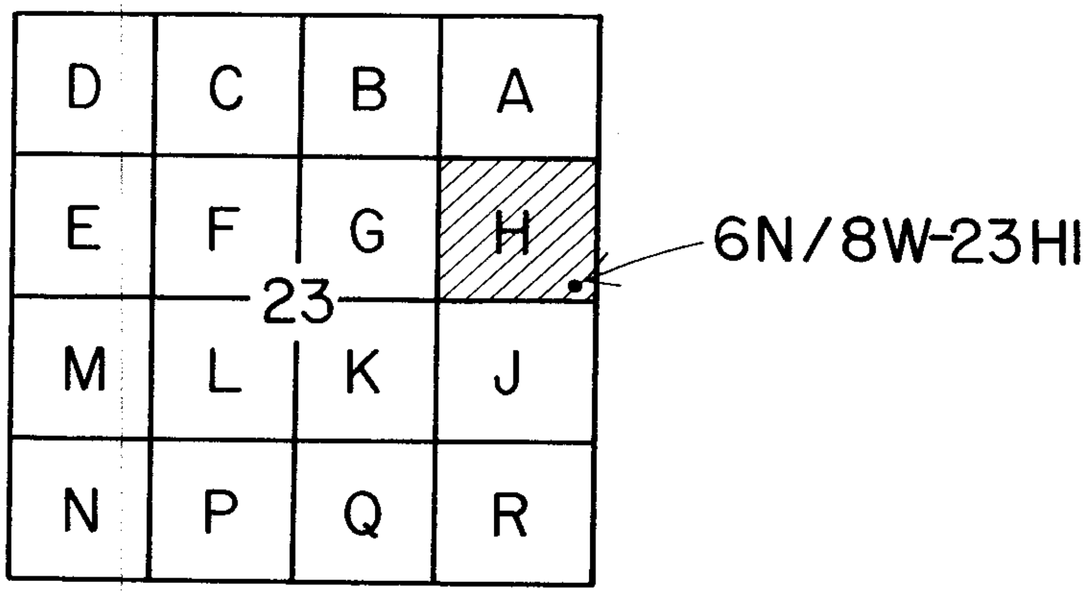
Soil maps developed by the U. S. Department of Agriculture Soil Conservation Service (Miller, 1972) were used to classify lands according to slope and soil permeability. Assuming that surface water is available, suitability of land for recharge is a function of its slope, which affects runoff time, and its infiltration rate. For this report, those soils on slopes of less than 15 percent and having an infiltration rate greater than 1.5 centimetres (0.6 inch) per hour have been tentatively classified as ground water recharge areas (after Muir and Johnson, 1979). Additional study may indicate that different infiltration rates may be more appropriate for this area.

During the course of this study, it was determined that ground water level and streamflow data for the model period (1960-1975) were not sufficient to completely calibrate and verify the model. Some suggestions for a data collection program to obtain the needed information are included in this report.

The water well numbering system used in this bulletin is based on the rectangular system of subdivision of public land. When Sonoma County was first settled, most valley lands became parts of 25 land-grant ranchos. Lands outside of the land grants became public lands and were surveyed into townships of 93 square kilometres (36 square miles) that were referenced to the Mount Diablo base and meridian. Each township was divided into 36 sections of roughly 2-1/2 square kilometres (one square mile) each. Because land-grant areas do not have surveyed township, range, and section lines, these lines have been projected into land grants for numbering water wells, and for other geographical identification.

A State well number has two basic parts: its township location and its section location. For example, Well 6N/8W-23H1 is located in Township 6 North, Range 8 West, and Section 23; this places the well in Rohnert Park. Each section is subdivided into 16 quarter-quarter sections of 16 hectares (40 acres) each; each 16-hectare tract is identified by a letter. Letters A through R are used, with letters I and O omitted to avoid confusion with similar appearing numbers. This particular well is in Tract "H", which can also be described as the southeast quarter of the northeast quarter of Section 23 (Figure 3). The final part of the well number is the sequential number of the well within that particular tract.

FIGURE 3



WELL NUMBERING SYSTEM

CHAPTER 2. CONCLUSIONS AND RECOMMENDATIONS

Major conclusions and recommendations of this study are summarized below.

Conclusions

- In the Santa Rosa Plain, alluvial fan deposits and the Merced Formation form the major water-yielding units. The ground water reservoir is extensively compartmentalized due to the discontinuous nature of most of the water-yielding units and to faulting, which thins water-yielding materials and may impede ground water flow.

- The total storage capacity of the Santa Rosa Valley ground water reservoir is estimated to be 5 320 000 cubic dekametres (dam^3) (4,313,000 acre-feet (ac-ft)). The thickness of the water-yielding materials ranges from 15 to 310 metres (m) (50 to 1,010 feet (ft)), with an average thickness of 120 m (400 ft). The total volume of ground water in storage as of spring 1980 was 4 823 000 dam^3 (3,910,000 ac-ft). This volume represents 91 percent of the total storage capacity, assuming that the reservoir could be filled to the ground surface, and includes water of all quality types. The ground water reservoir is, therefore, only about 9 percent dewatered.

- The volume of unsaturated ground water storage space available to accept additional water as of spring 1980 was estimated to be 497 000 dam^3 (403,000 ac-ft).

- Greater utility of natural water supplies may be possible by means of alternating or cyclical pumping and recharging, particularly in the vicinity of Santa Rosa.

- Ground water levels in southern Santa Rosa Plain declined as much as 0.8 m (2.7 ft) per year during the period from 1960 to 1975, while water levels near Santa Rosa rose about 0.2 m (0.7 ft) per year during the same period. Subsequent measurements of ground water from 1975 to 1981 indicate that the decline of ground water in southern Santa Rosa Plain continued until the above average precipitation of winter 1981-82. In piezometers built in 1977, as well as in a majority of Rohnert Park's municipal wells, ground water levels declined as much as 1.5 to 4.3 m (5 to 14 ft) per year until 1981. From 1981 to early 1982, water levels in 14 out of 18 of the Rohnert Park wells rose from one to as much as 13.1 m (43 ft), apparently in response to high winter rainfall and the decreased demand for applied water. The piezometers showed similar rises. The rainfall of winter 1981-82 was significantly higher than the average rainfall for the area so that such increases in water levels cannot be expected to occur year after year. The quick response of the wells indicates that some of the aquifers may be confined or semiconfined, with their water levels representing pressure surfaces. Such changing ground water levels warrant monitoring by ground water users in the area.

- The Santa Rosa Plain ground water basin as a whole is about in balance, with increased ground water levels in the northeast contrasting with decreased ground water levels in the south.

- The data available during this study were not sufficient to determine what amount of ground water could be extracted annually from the reservoir without drawing water levels down to the point of deleteriously affecting the ground water reservoir or the ground water itself. Determination of the amount of ground water that can be extracted over the long term will require better definition of the geologic sediments between areas of recharge and areas of extraction, continued monitoring of water levels in wells, aquifer tests in a number of wells to determine transmissivity, and monitoring of recharge in the basin.

° Data collected for the mathematical model of the Santa Rose Plain indicate that the volume of natural recharge from 1960 to 1975 was 541 800 dam^3 (439,200 ac-ft). Approximately half of the recharge takes place in permeable stream channels; the remaining recharge comes from deep percolation of rain falling on permeable soils.

° Total ground water pumpage during the 15-year modeling period from 1960 to 1975 for all purposes is estimated to be 549 200 dam^3 (445,300 ac-ft), distributed in this way:

Agricultural -- 322 900 dam^3 (261,800 ac-ft)

Rural Domestic -- 133 000 dam^3 (107,800 ac-ft)

Industrial -- 47 700 dam^3 (38,700 ac-ft)

Municipal -- 45 600 dam^3 (37,000 ac-ft)

° The recovery capabilities of parts of the ground water reservoir suggest that if more of the area's water demand were met by extracting ground water from areas of rapid recharge, more storage space would be available to accept surface runoff that is now rejected by the ground water reservoir. Such a change in pumping patterns might delay or decrease the need for additional import of surface water. At present, much water runs off the land surface as rejected recharge.

° Based on ground water quality data, the vertical and horizontal movement of water between aquifers ranges from good to poor. Generally, there is good vertical but poor horizontal continuity in the northern part of the reservoir, while both vertical and horizontal continuity are poor in the southern part. This may indicate the presence of geologic material that restricts the movement of ground water.

° Of the wells tested for water quality, few contained constituents over the recommended concentration for drinking water. Many wells produced water with esthetic problems, such as high concentrations of iron and manganese or high hardness. Questionnaires mailed to well owners indicated many complaints about the color and/or taste of ground water.

° Sea water intrusion is not a ground water quality problem in the Santa Rosa Plain and will probably not be in the future because of the distance of the valley from tidal action and a source of sea water in San Pablo Bay.

° The available data are not sufficient to define clearly the relationship between ground water pumping and the streams in the area. Unrestricted movement of ground water between the streambeds and the ground water reservoir appears to be minimal, except possibly adjacent to the channels and near Santa Rosa Creek and Laguna de Santa Rosa.

° Based on soil permeability and land slope, approximately 9 percent of the land surface in the Santa Rosa Plain is suitable for ground water recharge because of its high infiltration capacity. Aquifers beneath most natural recharge areas appear to be nearly full.

Recommendations

- Care should be exercised regarding intensive reliance on ground water as an unlimited source in Santa Rosa Plain. Potential problems related to movement of fresh ground water and increases in pumping costs should be recognized, and further planning for water resources management should be initiated to better foresee and optimize the hydraulic and economic responses to water use in the entire Santa Rosa Plain. This applies to the whole study area.

- Twenty-four-hour, constant-rate pump tests should be conducted so that the characteristics of the aquifers in the reservoir can be more accurately determined. This will assist in understanding the ground water system better and in calibrating the ground water model.

- The streamflow monitoring network, needed to better define the hydrology of the ground water reservoir for both the computer model and improved estimates of ground water recharge, should be implemented as soon as possible. The 112-well ground water level monitoring network recommended by Department of Water Resources as a modification of the existing monitoring-well grid should continue to be implemented to complete model verification, to improve estimates of the volume of ground water in storage, and to detect changes in the patterns of ground water use. These data will also assist in defining the hydraulic continuity between ground and surface water.

- Ground water pumping patterns in Santa Rosa Plain should be managed to optimize use of the ground water resource. Such management would reduce the possible need for artificial recharge.

- If artificial recharge becomes necessary, alternative methods and sites should be studied so that recharge is optimized. The only study, conducted by Sonoma County Water Agency, recommended an injection well near Todd Road.

- A program to measure the infiltration rate of soils should be implemented to more accurately assess the recharge capabilities of the Santa Rosa Plain.

- Ground water quality sampling should be conducted regularly near wells that pump water with quality problems. Sampling near the wells that are high in nitrate should be given priority. Future mineral sampling should be expanded to include iron and manganese.

- In addition to those recommendations relating to the Santa Rosa Plain ground water model, further steps should be taken to verify and improve the model so that it can be used as a water management tool. These steps, which are discussed in more detail in Chapter 7, are:

  - Adjust the model storage factors and the transmissivities between nodes so the computed water levels will more closely match the historical water levels.

  - Adjust the net recharge for each node within the accurcy of data.

  - Reevaluate the validity of historical water levels in nodes where historical and computed water levels do not match.

CHAPTER 3. OVERVIEW OF GROUND WATER GEOLOGY, HYDROLOGY, AND SOILS

This chapter presents a brief overview of the ground water geology, hydrology, and soils of the Santa Rosa Plain. A detailed description of these subjects has been published in Department of Water Resources Bulletin 118-4, Volume 1 (Ford, 1975).

Geology and Hydrology

Geologic formations in the Santa Rosa Plain can be divided into water-yielding formations, nonwater-yielding formations, and formations with highly variable water-yielding properties (Figure 4). Water-yielding formations are stream channel deposits, alluvium, alluvial fan deposits, and the Merced Formation. Water-yielding formations that generally produce only low yields of ground water are: basin deposits, the Glen Ellen Formation, and the Petaluma Formation. Yields from the Petaluma Formation are higher when a well intercepts a lens of gravel. The only nonwater-yielding formation in the study area is the Franciscan complex. The Sonoma and Tolay Volcanics have highly variable water-yielding properties; because of this variability, yields and the volume of ground water in storage in these units cannot be estimated as accurately as for other units.

Table 1 summarizes geologic and hydrologic characteristics of these units and their specific yields. Plate 1 shows the areal distribution of these units. The subsurface distribution of these units has been determined along the cross section lines indicated on Plate 1 and Figure 5A as A-A', B-B', C-C', and D-D'. Figures 5B-E show profiles of the four cross sections. The following paragraphs briefly describe the geologic units, beginning with the oldest rocks.

In the following geologic descriptions, well yields have been described as limited or low, moderate, and high yields. "Limited" or "low" yield means yields generally range from 5 to 380 litres per minute (L/min) (1 to 100 gallons per minute (gal/min)). With such yields, dry holes are common. "Moderate" yields generally range from 380 to 1 100 L/min (100 to 300 gal/min). "High" yields generally exceed 1 100 L/min (300 gal/min). The yield of a formation is directly related to the hydraulic conductivity of the formation it penetrates. For more information on well yields, see Ford (1975).

Franciscan Complex

The Franciscan complex is the oldest geologic unit in the study area (Jurassic and Cretaceous age -- see Figure 6). It is exposed in the mountainous region on the western edge of the study area. The complex includes highly variable amounts of shale, sandstone, chert, greenstone, and serpentinite. The Franciscan complex generally contains only limited quantities of water in fractures. Normally, consolidated rocks containing water only in fractures are not considered to have a specific yield. However, for this report, the Franciscan complex has been assigned a very low apparent specific yield of less than 3 percent. Because of the very low specific yield, areas composed of the Franciscan complex were not included in calculations of storage capacity in Chapter 4.

Tolay Volcanics

The Tolay Volcanics is of Miocene to early Pliocene age. Although exposed in the vicinity of Petaluma, the Tolay

Volcanics is not exposed in the study area. It extends beneath the southern Santa Rosa Plain at a depth of 650 m (2,100 ft).

The unit, defined by Morse and Bailey (1935) from oil well core samples, includes a great thickness of lava flows, breccias, tuffs, and agglomerates. In some areas west of Petaluma, stream channel deposits are interbedded with the volcanic flow rocks.

The Tolay Volcanics has a highly variable specific yield. It is considered to be a fair-to-good water producer in some areas west of the City of Petaluma (Ford, in progress). In other parts of Petaluma Valley, the lava flows are essentially nonwater-yielding except where the rocks have been highly fractured by faults. Normally, consolidated rocks containing water only in fractures are not considered to have a specific yield. However, for this report, the Tolay Volcanics has been collectively assigned a variable apparent specific yield of from 0 to 10 percent. Because of the variable water-yielding characteristics, areas composed of the Tolay Volcanics were not included in calculations of storage capacity in Chapter 4.

Petaluma Formation

The Petaluma Formation, mid-to-late Pliocene in age, is exposed along the southwestern and southeastern edges of the study area. The Petaluma Formation consists of folded continental and shallow marine to brackish-water deposits of clay, shale, and sandstone, with lesser amounts of conglomerate and nodular limestone. Occasional thick beds of diatomite are present. Abundant clay characterizes this unit; Weaver (1949) measured a 323-m (1,059-ft) thick stratigraphic section near Lakeville in the Petaluma Valley containing 70 percent clay, shale, and clayey or shaley beds. Hydrogen sulfide has been found within the Petaluma Formation northwest of Rohnert Park, as recorded in Sonoma County Water Agency water well logs.

The Petaluma Formation can yield moderate amounts of water when a well penetrates an appreciable thickness of sand and gravel. However, because of the large amounts of clay that characterize the unit, the Petaluma Formation has been assigned a low overall specific yield of from 3 to 7 percent.

Merced Formation

The Merced Formation, generally Miocene to Pliocene in age, is one of the principal water-yielding formations in Sonoma County. It is exposed in the uplands on the western side of the Santa Rosa Plain and extends into the plain beneath the alluvial fan deposits at depths ranging from 60 to 180 m (200 to 600 ft). Beneath the Santa Rosa Plain, the Merced Formation averages 150 m (500 ft) thick.

As exposed in the western uplands, the Merced is a shallow marine deposit consisting predominantly of massive beds of coarse- to fine-grained sandstone containing some fossiliferous beds; gravel lenses and thin interbeds of clay and silty clay are also present. Well log data indicate that the percentage of clay in the formation increases toward the southern end of the valley. Some ground water within the Merced Formation is semiconfined to confined because of isolated clay lenses.

Marine fossils are abundant within the Merced and are generally recorded as clamshells or oysters on water well drillers' logs. Also common within the formation are zones of poorly consolidated, very fine sand, frequently reported by drillers as "quicksand". High concentrations of methane gas have been noted in the Merced in the central portion of the valley. Since the Merced is predominantly sandstone, it has a high specific yield of from 10 to 20 percent.

FIGURE 4

GROUND WATER TERMINOLOGY

The science of ground water hydrology deals with the distribution and behavior of ground water -- how much water is contained in any geologic material and how easily it can be extracted. The science of ground water geology deals with the effect of geology on the distribution and movement of ground water -- how different geologic materials and geologic structures determine the rate and paths of movement of ground water. By knowing the geology of an area, the subsurface hydraulic properties of that area can be estimated, because ground water hydrology and ground water geology are closely related.

Geologic formations can be divided into two groups: water-yielding and nonwater-yielding. Water-yielding formations, which usually consist of unconsolidated deposits of sand and gravel, readily absorb, transmit, and yield large quantities of ground water to wells. Nonwater-yielding formations, which usually consist of clay and consolidated rocks, yield only limited quantities of water to wells. Each geologic formation has specific hydraulic properties: porosity, permeability, specific yield, and transmissivity.

POROSITY AND PERMEABILITY

Porosity is the ratio of the volume of the voids between the particles in a sample to the total volume of the sample.

$$\text{Porosity} = \frac{\text{volume of voids}}{\text{total volume of sample}} (100) = \%$$

Porosity is not necessarily indicative of permeability, which indicates the ease with which ground water moves through a material. If the openings between the particles are small or are not connected, the permeability of the material is low. For example, clay contains a large number of small voids, so its porosity may be as high as 50 percent. Because of the physical and chemical nature of clay, it transmits very little water and it has a very low permeability, about 1.07×10^{-4} metres (3.5×10^{-4} feet) per day.* The porosity of sand and gravel is about 20 percent, much lower than the porosity of clay, but the voids in the sand and gravel are larger and are interconnected. Thus, most sands and gravels transmit water readily, having a permeability of about 1.07×10^{2} metres (3.5×10^{2} feet) per day.

A permeable geologic unit is called an aquifer. A relatively impermeable geologic unit is called an aquiclude or an aquitard because it retards the flow of water; both are called confining beds because they block the movement of ground water. Confining beds usually consist of clay or other fine-grained sediments. They contain ground water but have low permeability and cannot transmit extractable quantities. Granite is an example of an aquifuge because ground water cannot flow through it; granite is neither porous nor permeable. Ground water does flow through joints in the granite, but that geologic complication is a result of structural complexities not related to porosity or permeability. The porosity and permeability of formations composed of clay, sands, and gravels generally decrease through time as the formation becomes more consolidated.

SPECIFIC YIELD

Specific yield is the ratio of the volume of water that will drain due to gravity from a saturated sample of material to the total volume of the sample.

$$\text{Specific Yield} = \frac{\text{volume of water drained}}{\text{total volume of sample}} (100) = \%$$

The higher the specific yield of a geologic unit, the more water it will yield. Listed below are representative specific yield values for common geologic materials. Geologic materials having a more uniform grain size distribution will have a greater specific yield because of the greater total amount of space between particles. Consolidated rock and rocks such as basalt and granite are given specific yield values close to zero because water is contained only in fractures and not within the rock. The volume of water stored in fractured rock is highly variable, depending on the size and extent of the fractures, and cannot be easily quantified.

% Specific Yield	3	5	10	20	25
Geologic Material	Adobe Clay Shale	Cemented Gravel Cemented Sand Clay and Gravel Silt	Clay, Sand, & Gravel Fine Sand Quicksand Sand and Clay	Coarse Sand Loose Sand Medium Sand	Gravel Sand and Gravel

TRANSMISSIVITY

Transmissivity is the rate at which ground water will flow through a unit width of an aquifer, and is equal to the permeability of an aquifer multiplied by its thickness. The transmissivity of an aquifer or formation can generally be determined only from water level data collected during extended pumping of a water well. During a constant-rate pump test, abrupt changes in the slope of the curve from which transmissivity is determined indicate either the presence of a barrier, which impedes ground water movement, or the presence of a source of ground water recharge.

*"Metres per day" and "feet per day" are standard velocity units that indicate the amount of ground water that moves through a given cross-sectional area in one day:
a. 1 cubic metre of ground water moves through 1 square metre in 1 day. The units are: $1 \text{ m}^3 / \text{m}^2 / \text{day} = 1 \text{ m/day}$
b. 1 cubic foot of ground water moves through 1 square foot in 1 day. The units are: $1 \text{ ft}^3 / \text{ft}^2 / \text{day} = 1 \text{ ft/day}$

TABLE 1

HYDROLOGIC EVALUATION OF GEOLOGIC UNITS IN THE SANTA ROSA PLAIN

Geologic Unit	Lithology[1/]	Specific Yield	Comments
Stream Channel Deposits	Sand and gravel	High (15-20%)	
Bay Mud Deposits	Mud, rich in organic matter, silty mud, silt and sand	Low (3-7%)	Low Yields.
Alluvium	Sand, silt, clay, and gravel	Variable (3-15%)	
Alluvial Fan Deposits	Fine sand, silt, and silty clay, coarse sand and gravel, with gravel more abundant near fan heads	Moderate to high (8-17%)	Minor amounts of methane gas. Lenses of very fine sand.
Glen Ellen Formation	Gravel, sand, silt and clay, local inter-bedded tuff	Low (3-7%)	Generally low yields.
Sonoma Volcanics	Volcanic flows, agglomerates, and tuffs	Highly Variable (0-15%)	Variable yields. Some water has high boron content. Some waters thermal. Zones of high concentration of hydrogen sulfide (H_2S).
Merced Formation	Coarse-to-fine-grained sandstone with minor amounts of clay.	High (10-20%)	Minor amounts of hydrogen sulfide (H_2S). Lenses of very fine sand. Zones of high concentration of methane gas.
Petaluma Formation	Clay and shale with minor amounts of sandstone	Low (3-7%)	Generally low yields. Yields may be higher for wells penetrating lenses of coarse material. Zones of hydrogen sulfide (H_2S).
Tolay Volcanics	Volcanic flows, tuffs, breccias and agglomerates	Unknown Assumed to be very low (<3%)	Little data available about formation.
Franciscan Complex	Includes chert, sand-stone, shale, green-stone, and serpentinite	Apparent specific yield is very low (<3%)	Poor quality water in thermal areas, serpentinite, low yields.

1/ Data from Blake, et al (1971) and Fox, et al (1973).

Figure 5A

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

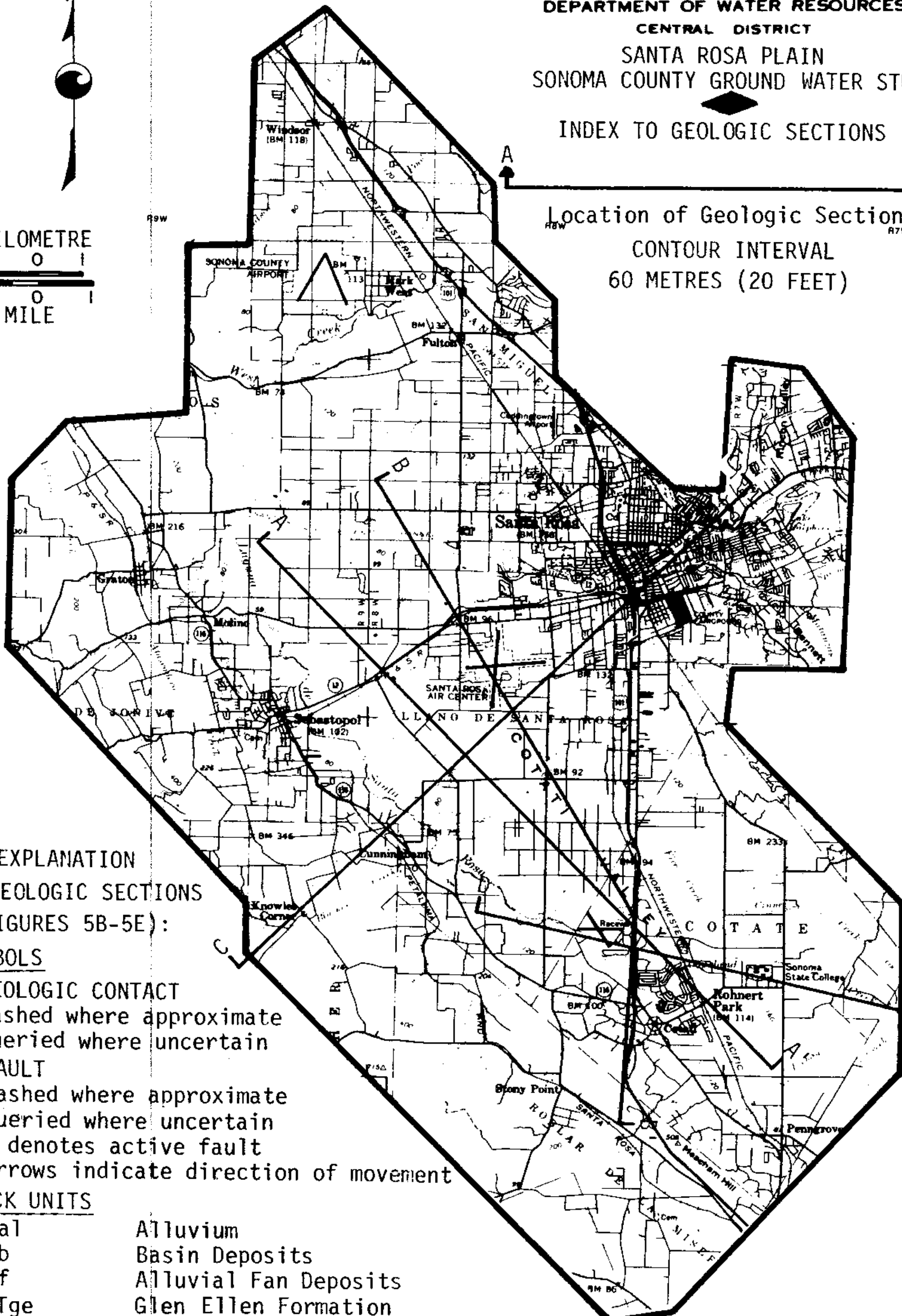
SANTA ROSA PLAIN
SONOMA COUNTY GROUND WATER STUDY

INDEX TO GEOLOGIC SECTIONS

A — A' Location of Geologic Section

CONTOUR INTERVAL
60 METRES (20 FEET)

KILOMETRE 1 0 1
1 0 1 MILE



EXPLANATION
FOR GEOLOGIC SECTIONS
(FIGURES 5B-5E):

SYMBOLS

— - -?- GEOLOGIC CONTACT
dashed where approximate
queried where uncertain

⇌ ✱ -?- FAULT
dashed where approximate
queried where uncertain
X denotes active fault
arrows indicate direction of movement

ROCK UNITS

Qal	Alluvium
Qb	Basin Deposits
Qf	Alluvial Fan Deposits
QTge	Glen Ellen Formation
Tsv/Tst	Sonoma Volcanics
Tp	Petaluma Formation
Tm	Merced Formation
Ttv	Tolay Volcanics
KJf	Franciscan Complex

SEE PLATE 1 FOR DETAILED DESCRIPTION OF ROCK UNITS.

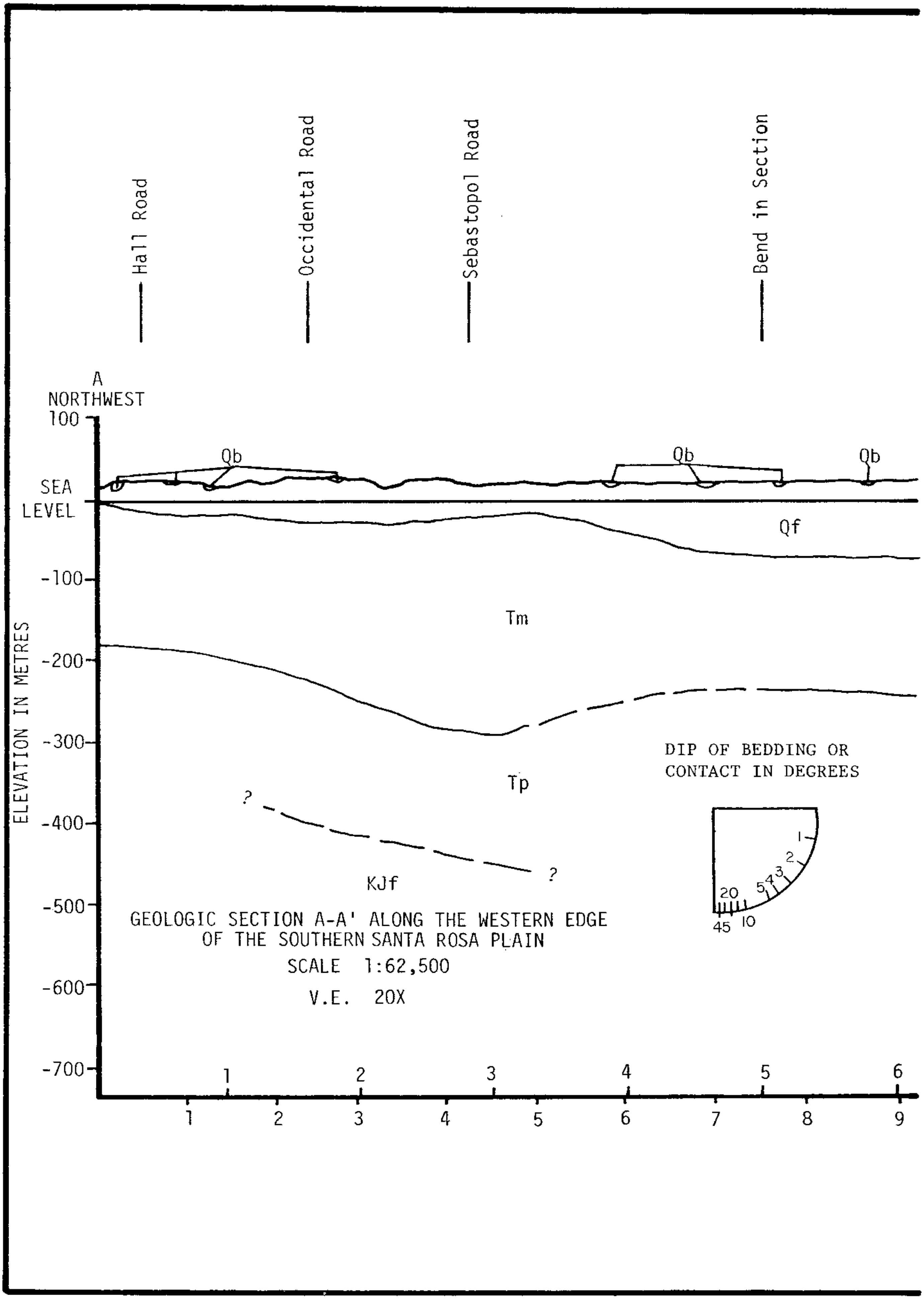
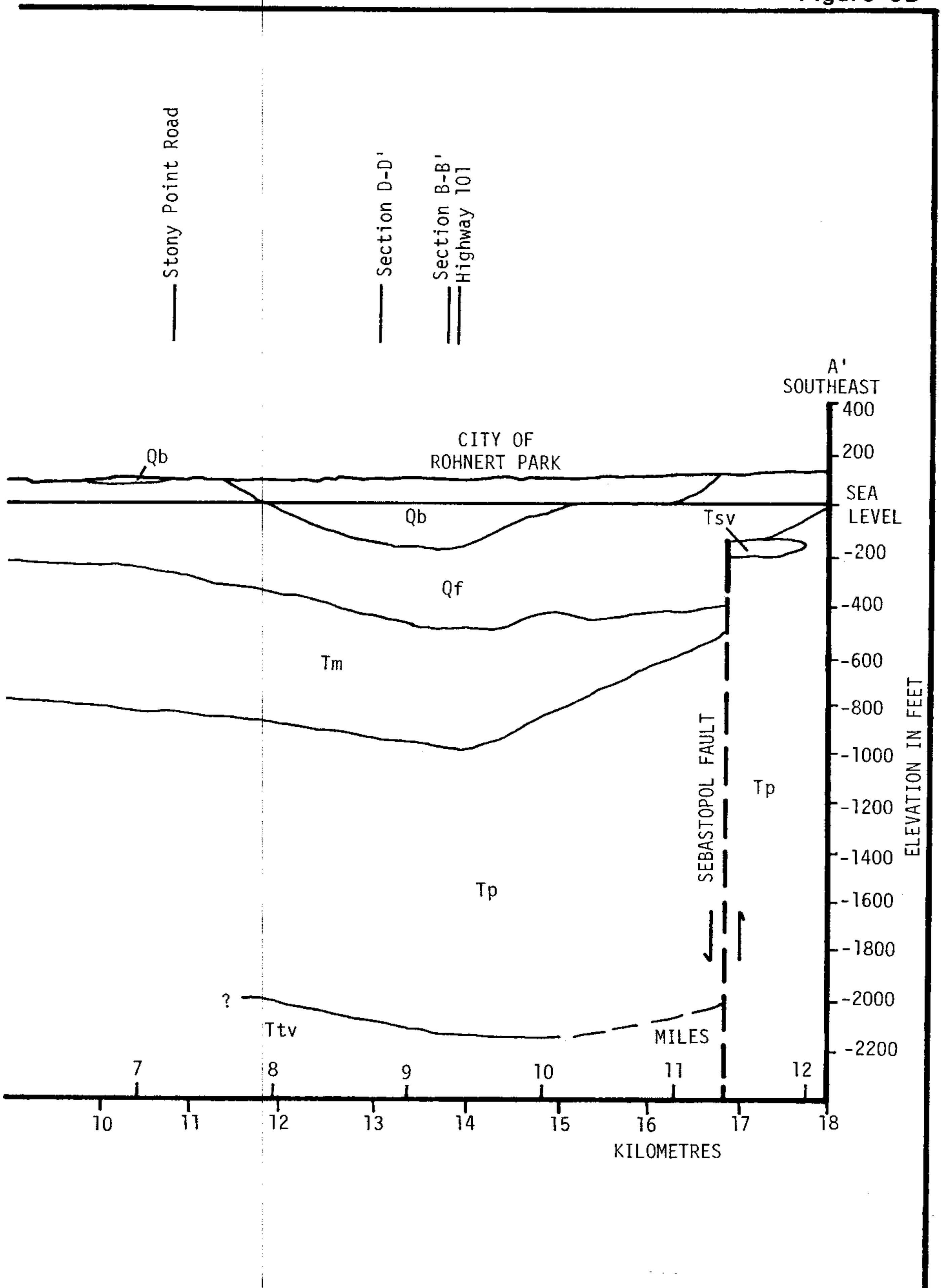

Hall Road
Occidental Road
Sebastopol Road
Bend in Section
A
NORTHWEST
100
SEA LEVEL
-100
-200
-300
-400
-500
-600
-700
ELEVATION IN METRES
Qb
Qb
Qb
Qf
Tm
Tp
KJf
?
?
DIP OF BEDDING OR CONTACT IN DEGREES
1
2
3
4
5
10
20
45
1 2 3 4 5 6
1 2 3 4 5 6 7 8 9
GEOLOGIC SECTION A-A' ALONG THE WESTERN EDGE OF THE SOUTHERN SANTA ROSA PLAIN
SCALE 1:62,500
V.E. 20X

Figure 5B


Stony Point Road
Section D-D'
Section B-B'
Highway 101
A'
SOUTHEAST
CITY OF
ROHNERT PARK
Qb
Qb
Tsv
Qf
Tm
Tp
Tp
SEBASTOPOL FAULT
?
Ttv
MILES
7
8
9
10
11
12
10
11
12
13
14
15
16
17
18
KILOMETRES
400
200
SEA
LEVEL
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
-2200
ELEVATION IN FEET

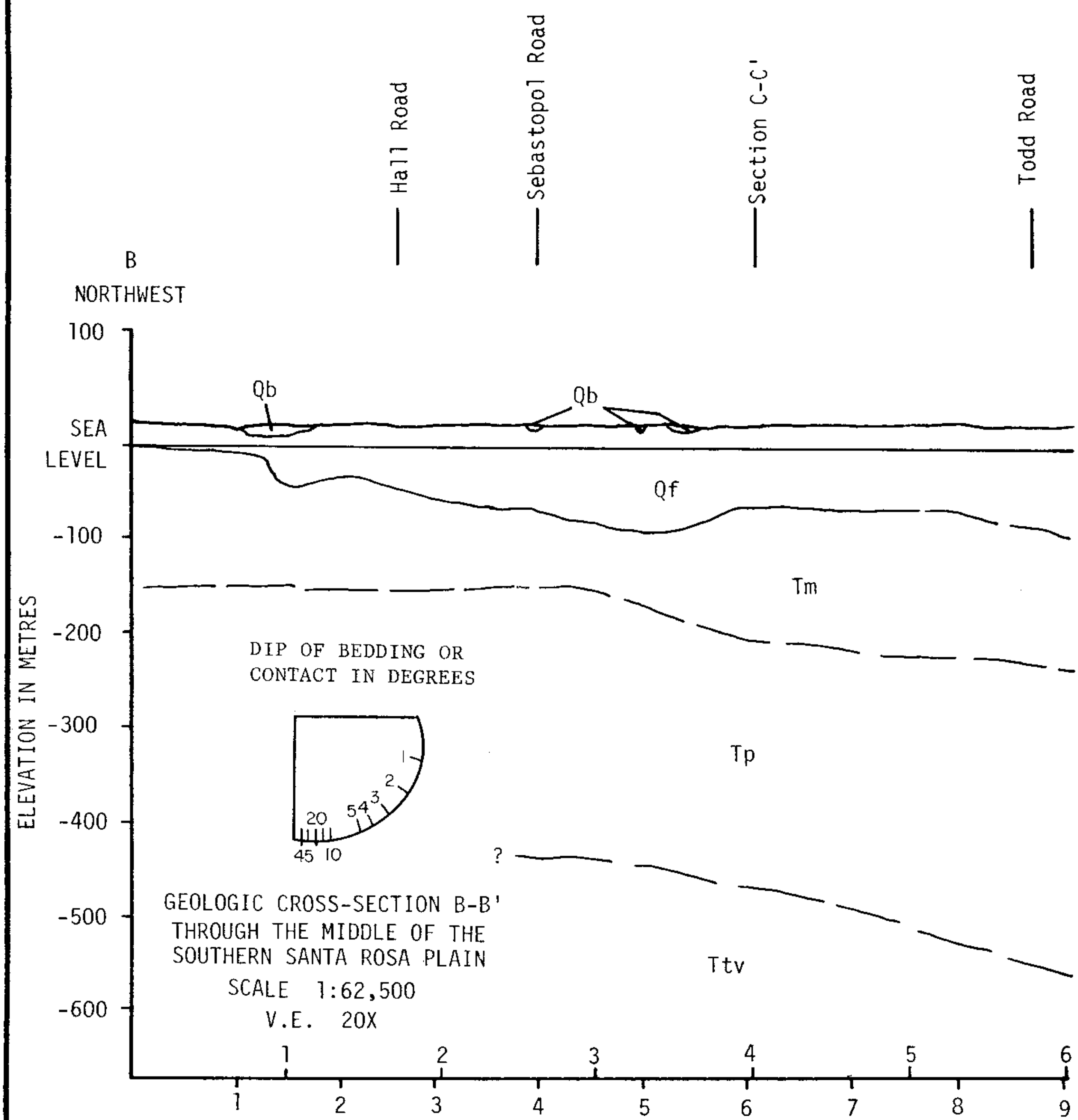
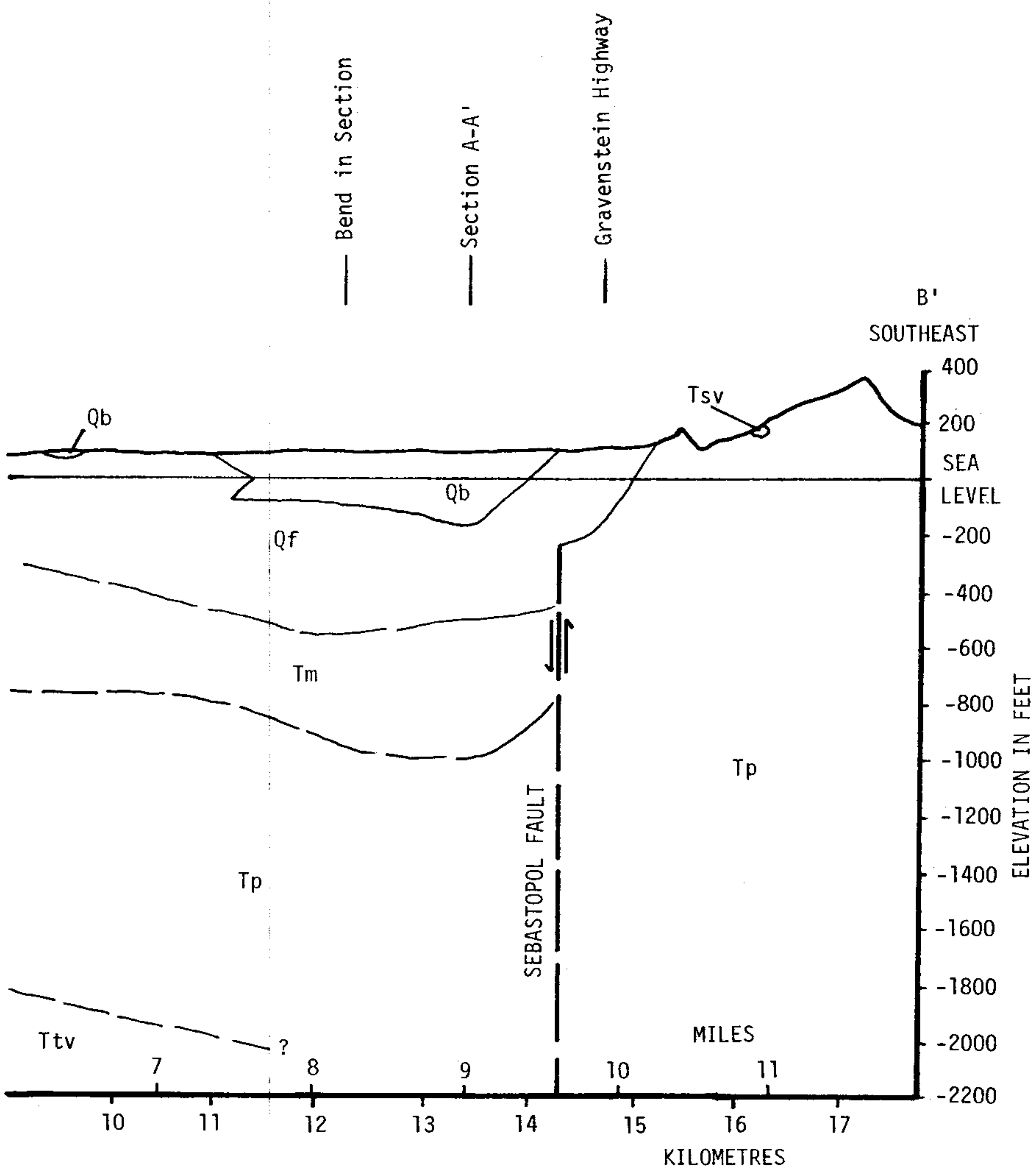
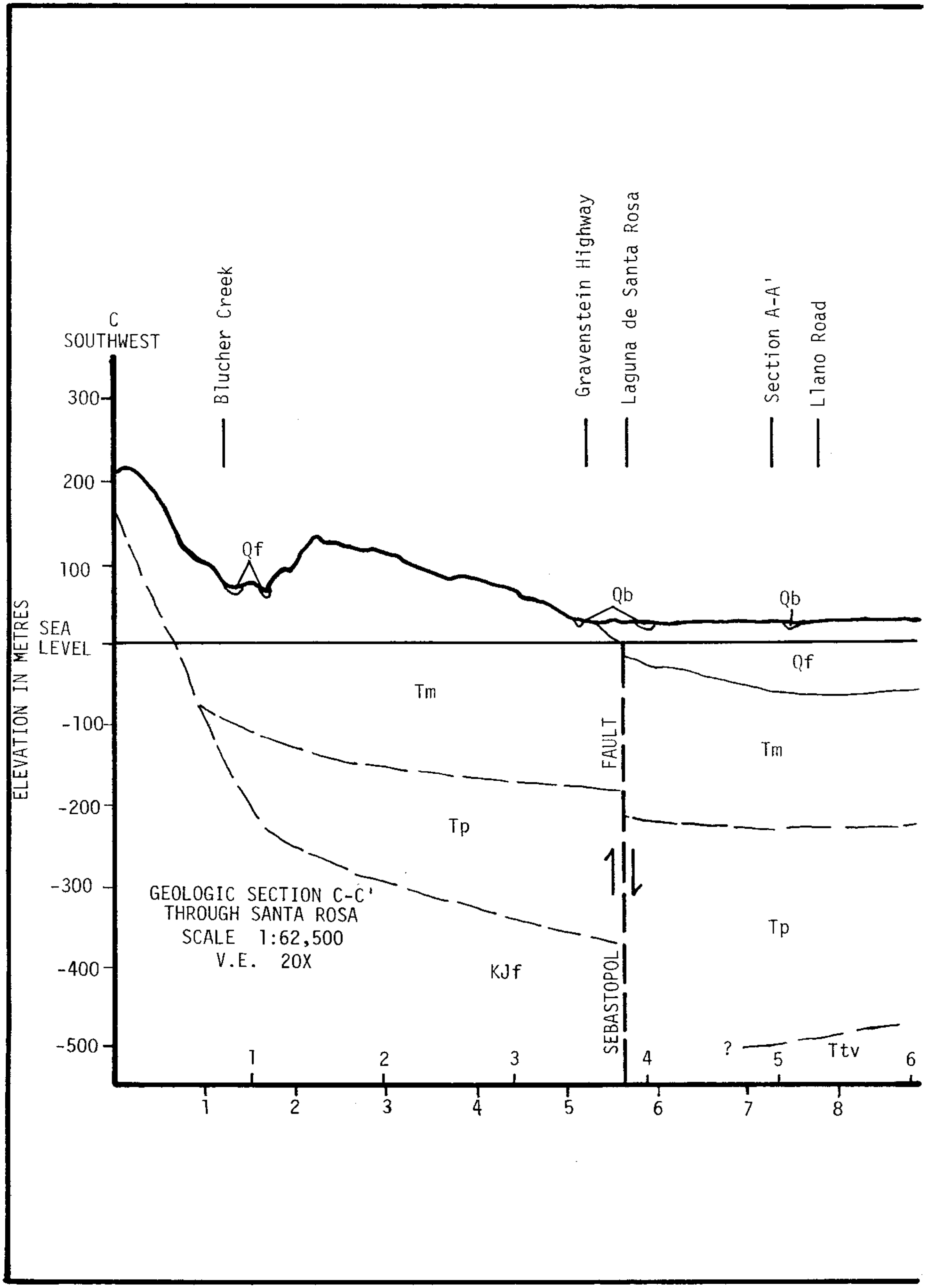
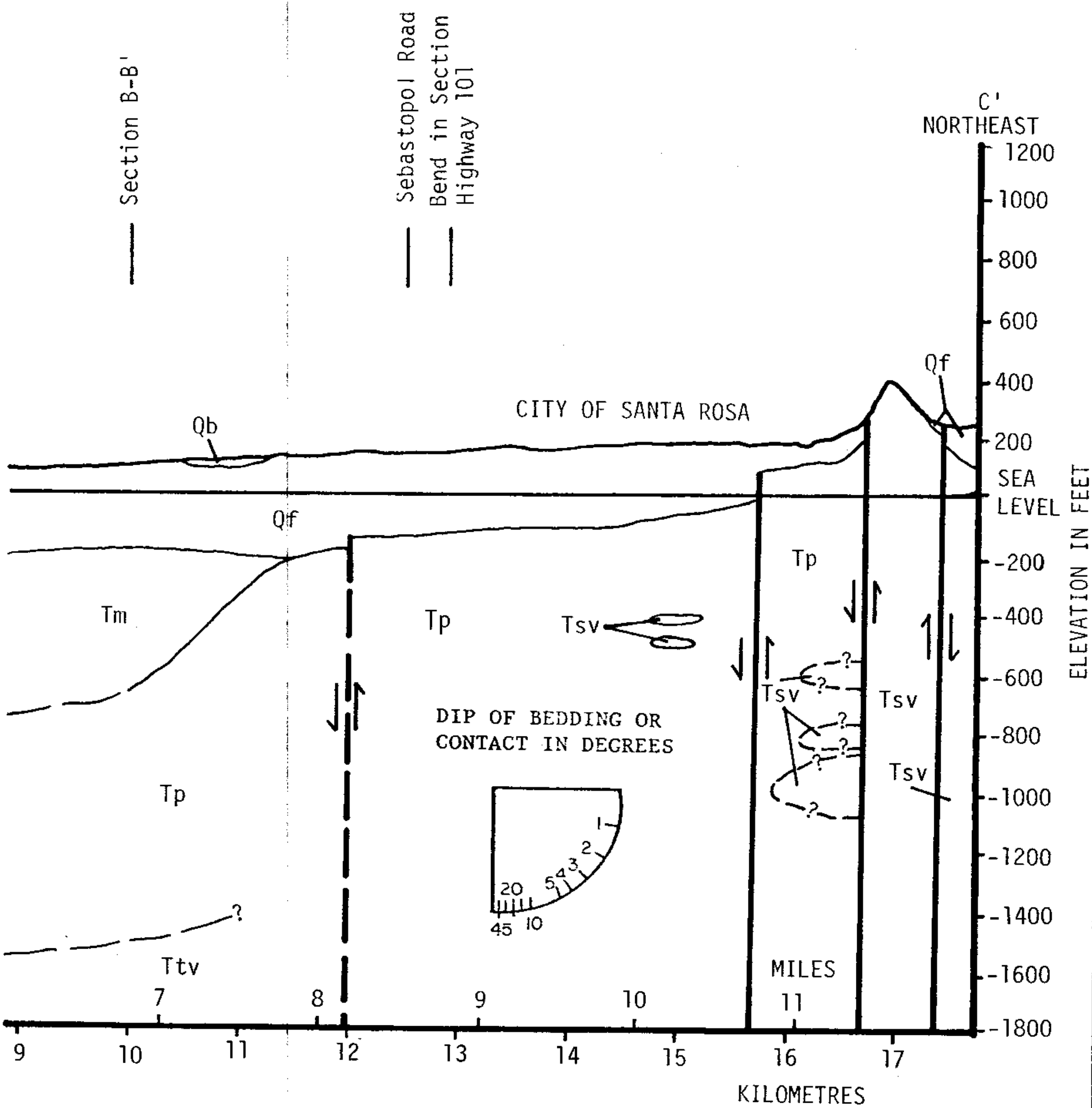

Hall Road
Sebastopol Road
Section C-C'
Todd Road
B
NORTHWEST
100
SEA
LEVEL
-100
-200
-300
-400
-500
-600
ELEVATION IN METRES
Qb
Qb
Qf
Tm
Tp
Ttv
?
DIP OF BEDDING OR
CONTACT IN DEGREES
1
2
3
4
5
20
45
10
GEOLOGIC CROSS-SECTION B-B'
THROUGH THE MIDDLE OF THE
SOUTHERN SANTA ROSA PLAIN
SCALE 1:62,500
V.E. 20X
1 2 3 4 5 6
1 2 3 4 5 6 7 8 9

Figure 5C


Bend in Section
Section A-A'
Gravenstein Highway
B'
SOUTHEAST
400
200
SEA
LEVEL
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
-2200
ELEVATION IN FEET
Qb
Tsv
Qb
Qf
Tm
Tp
Tp
SEBASTOPOL FAULT
Ttv
?
MILES
7
8
9
10
11
10
11
12
13
14
15
16
17
KILOMETRES



C
SOUTHWEST
Blucher Creek
Gravenstein Highway
Laguna de Santa Rosa
Section A-A'
Llano Road
ELEVATION IN METRES
300
200
100
SEA LEVEL
-100
-200
-300
-400
-500
Qf
Qb
Qb
Qf
Tm
Tm
Tp
Tp
KJf
Ttv
?
FAULT
SEBASTOPOL
GEOLOGIC SECTION C-C'
THROUGH SANTA ROSA
SCALE 1:62,500
V.E. 20X
1
2
3
4
5
6
1
2
3
4
5
6
7
8


Section B-B'
Sebastopol Road
Bend in Section
Highway 101
C'
NORTHEAST
1200
1000
800
600
400
200
SEA LEVEL
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
ELEVATION IN FEET
Qf
CITY OF SANTA ROSA
Qb
Qf
Tp
Tm
Tp
Tsv
Tsv
Tsv
Tsv
DIP OF BEDDING OR
CONTACT IN DEGREES
1
2
3
4
5
10
20
45
Tp
Ttv
MILES
7
8
9
10
11
9
10
11
12
13
14
15
16
17
KILOMETRES

3—76048

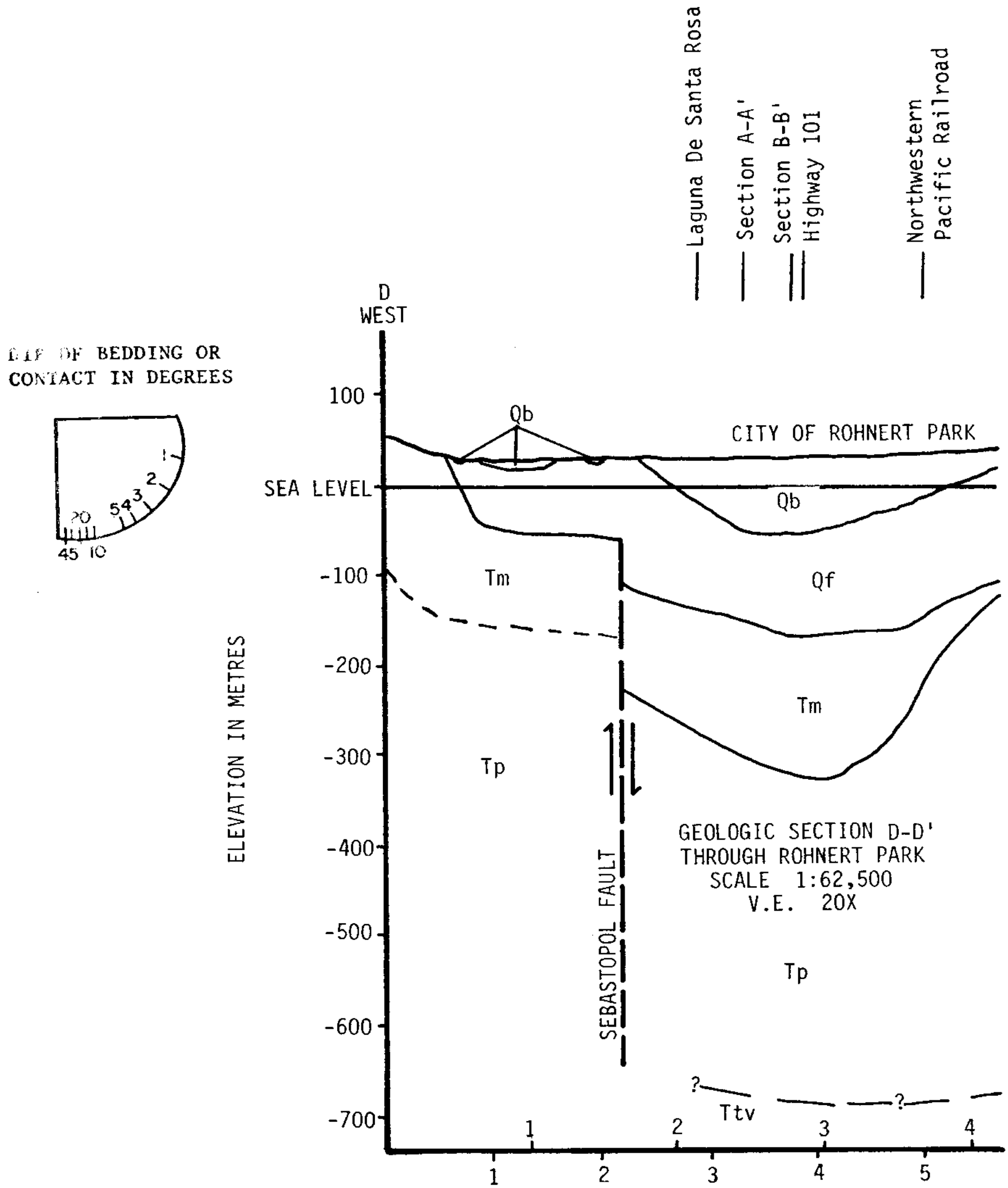
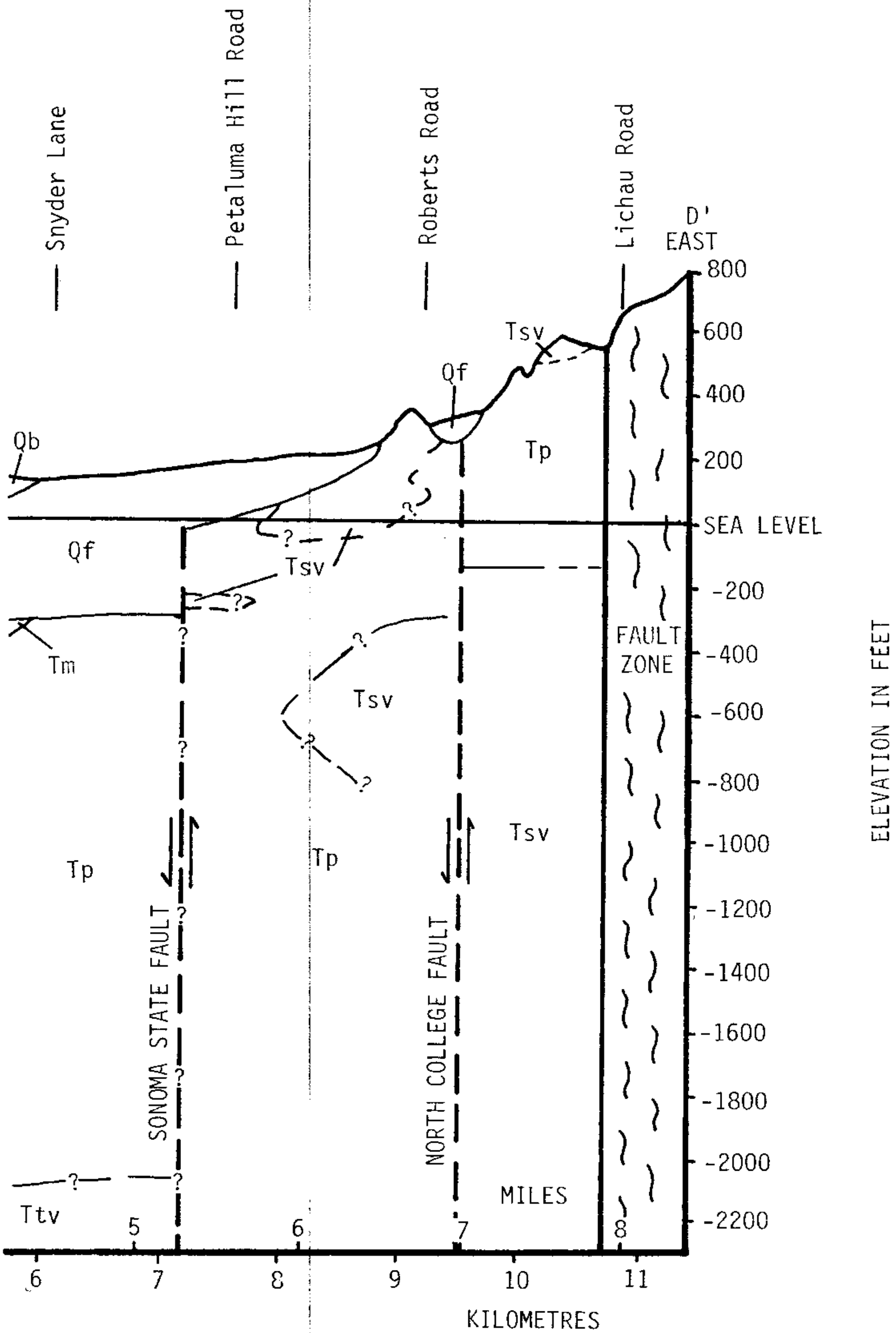
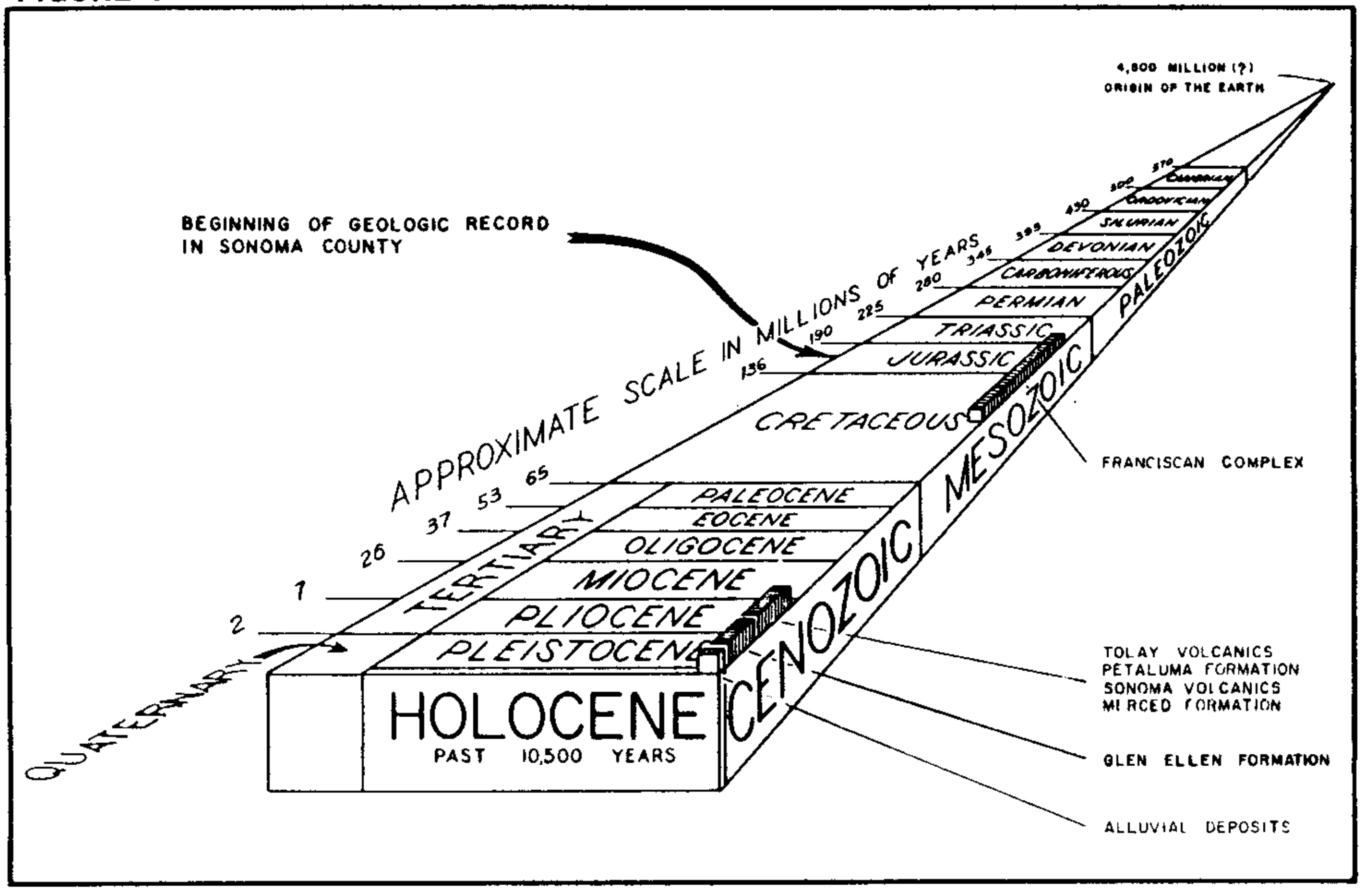

Laguna De Santa Rosa
Section A-A'
Section B-B'
Highway 101
Northwestern Pacific Railroad
D
WEST
DIP OF BEDDING OR CONTACT IN DEGREES
100
SEA LEVEL
-100
-200
-300
-400
-500
-600
-700
ELEVATION IN METRES
Qb
CITY OF ROHNERT PARK
Qb
Qf
Tm
Tm
Tp
Tp
Ttv
SEBASTOPOL FAULT
GEOLOGIC SECTION D-D'
THROUGH ROHNERT PARK
SCALE 1:62,500
V.E. 20X

Figure 5E



Snyder Lane
Petaluma Hill Road
Roberts Road
Lichau Road
D'
EAST
Qb
Qf
Tsv
Tp
Qf
Tsv
Tm
Tsv
Tp
Tsv
Tp
FAULT ZONE
SONOMA STATE FAULT
NORTH COLLEGE FAULT
Ttv
MILES
5
6
7
8
800
600
400
200
SEA LEVEL
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
-2200
ELEVATION IN FEET
6
7
8
9
10
11
KILOMETRES

FIGURE 6



LOOKING BACK IN GEOLOGIC TIME—SANTA ROSA PLAIN

Sonoma Volcanics

The Sonoma Volcanics, of Pliocene age, is exposed in the Sonoma Mountains, which border the Santa Rosa Plain on the east. Generally, the Sonoma Volcanics consist of a thick sequence of lava flows (labeled Tsv on Plate 1) with minor intrusive igneous rocks consisting of rhyolite, perlite, and rhyolite breccia. In some areas, lava flows are interlayered with tuff, welded tuff, and volcanic sedimentary deposits, such as tuffaceous sand and volcanic gravel (labeled Tst on Plate 1). Large landslides have been mapped by Fox, et al. (1973) in areas underlain by Sonoma Volcanics.

The Sonoma Volcanics has a highly variable specific yield. It is considered to be a good water producer where unwelded tuff, scoria, and volcanic sediments are present. The lava flows and intrusive rocks are essentially nonwater-yielding except where the rocks have been highly fractured. Normally, consolidated rocks containing water only in fractures are not considered to have a specific yield. However, for this report, the Sonoma Volcanics has been collectively assigned a variable apparent specific yield of from 0 to 15 percent. Because of the variable water-yielding characteristics, areas composed of Sonoma Volcanics were not included in calculations of storage capacity in Chapter 4.

Glen Ellen Formation

The Glen Ellen Formation, of Pliocene (?) and Pleistocene age, is exposed along the north and northwestern margins of the Santa Rosa Plain. It is composed of partially cemented gravel, sand, silt, and clay, and locally contains much interbedded tuff. Obsidian pebbles are characteristic of the Glen Ellen. The Glen Ellen Formation represents older, more consolidated alluvial fan deposits.

In the past, many surficial deposits of the northern and central Santa Rosa Plain have been identified as Glen Ellen. Fox, et al. (1973) identified only isolated exposures within the study area as belonging to the Glen Ellen Formation, and his nomenclature is followed here. In the remainder of the study area, the Glen Ellen of Cardwell (1958) used in DWR Bulletin 118-4, Volume 1 (Ford, 1975) has been identified as alluvial fan and basin deposits.

Because of the cementation of the gravels, the amount of clay present, and the degree of consolidation of the formation, well yields are low and many wells are dry. The specific yield is believed to be low, ranging from 3 to 7 percent.

Alluvial Fan Deposits

Alluvial fan deposits of Pleistocene and Holocene age form a nearly continuous blanket over the Santa Rosa Plain. The deposits consist of poorly sorted coarse sand and gravel and moderately sorted fine sand, silt, and silty clay; gravel content increases near the heads of the fans.

Lenses of very fine sand within the alluvial fan deposits frequently cause sanding problems in water wells. This sand is similar to the very fine-grained sand present in the Merced Formation; the Merced may be, in part, a source of this alluvial fan sand.

Minor amounts of methane gas have been noted in fan deposits in the southern Santa Rosa Plain. The gas may have risen from an underlying formation, such as the Merced, and been trapped within the fan deposits by overlying impermeable clay.

Because of the unconsolidated, coarse-grained nature of much of the alluvial fan deposits, they have been given a moderate to high specific yield of 8 to 17 percent.

Alluvium and Stream Channel Deposits

A variety of alluvial materials of Pleistocene to Holocene age are present in the Santa Rosa Plain as discontinuous deposits. Older alluvium is present north of Rohnert Park; large deposits of younger alluvium occur along Windsor, Mark West, Santa Rosa, and Atascadero creeks. Both younger and older alluvium are composed of interbedded sand, silt, clay, and gravel. The specific yield of these deposits is variable, depending on the amount of clay present and the thickness of the deposit. Most are less than 30 m (100 ft) thick with specific yields ranging from 3 to 15 percent.

Stream channel deposits are alluvial deposits of sand and gravel that formed in the beds of major rivers. The Russian River channel contains the largest deposit in the area. Because of the coarse-grained, unconsolidated nature of stream channel deposits, they have a very high specific yield of 15 to 20 percent.

Basin Deposits

Shallow basin deposits of Pleistocene and Holocene age cover the central portion of the southern Santa Rosa Plain, extending northward along the Laguna de Santa Rosa. Fox (1973) described the unit as marsh-like deposits, composed of poorly sorted dark clay and silty clay, both rich in organic matter. Because of the large percentage of clay they contain, basin deposits produce little ground water, and they may impede infiltration and downward percolation of water. Basin deposits have a low specific yield of from 3 to 7 percent.

Folds and Faults

Ground water reservoirs can be modified by folds and faults. Layered geologic formations can be bowed upward and downward by regional geologic forces to form anticlines and synclines, respectively. Because the hydraulic conductivity in these formations prior to folding is usually highest along bedding planes and lowest perpendicular to bedding planes, ground water usually flows away from the axis, or core, of an anticline and toward the axis of a syncline. In both cases, this is the direction of highest hydraulic conductivity.

Two major folds are believed to exist in the Santa Rosa Plain. The Windsor Syncline extends from Windsor south to the vicinity of Fulton. The Adobe Creek Anticline is southeast of the study area, but may be the feature that separates the Santa Rosa Plain and Petaluma Valley. Many smaller folds have been mapped in the study area in the Petaluma Formation. No large folds have been mapped in the Merced Formation in the study area; the Merced as a whole dips slightly to the east. Small folds have been mapped in the Glen Ellen Formation in some areas in Sonoma County. Younger geologic formations have not been folded.

Faults are fractures in the rock along which the rocks on either side have been moved. The fracture might or might not intersect the earth's surface. Faults are widespread in the Santa Rosa Plain and surrounding mountains. Faults sometimes create zones of crushed and broken rock along the fault plane. This crushed material, known as gouge, consists of clay-sized particles and can impede the movement of ground water across the fault, thus acting as a ground water barrier. Faults can also affect ground water movement by thinning water-yielding sands and gravels on the upthrown side of the fault; higher topographic relief increases the rate of erosion. Water-yielding materials may be thicker on the downthrown side if sediments are being deposited during a period of continued downward movement of one side of the fault.

Major faults in the Santa Rosa Plain study area are (from north to south): the Healdsburg, Rodgers Creek, North College, Sebastopol, Tolay, Meacham Hill, and Bloomfield.

The active Healdsburg and Rodgers Creek faults are part of a zone of faulting just west of the crest of the Sonoma Mountains. The 1969 earthquake that extensively damaged Santa Rosa was centered on the Rodgers Creek fault. Because of the locations of these faults, they probably have little effect on aquifers beneath the valley floor. Because the faults may impede the flow of recharging ground water moving downslope toward the valley, and because many of the rocks in the mountainous areas are essentially nonwater-yielding, areas east of the Healdsburg and Rodgers Creek fault traces were not included in calculations of storage capacity in Chapter 4.

The North College fault extends beneath the alluvial fan deposits on the eastern side of the Santa Rosa Plain. The fault has reduced the thickness of fan deposits east of the fault trace because of its influence on now-buried topography. The North College fault does not appear to directly influence ground water.

The Sebastopol fault extends along the base of the western uplands in the study area. It is believed to act as a ground water barrier based on data collected during a pump test of the Sonoma County Water Agency Todd Road Emergency Well (6N/8W-7A2).

The traces of the Tolay, Meacham Hill, and Bloomfield faults cross the southwestern edge of the study area. The effect of the Tolay and Bloomfield faults on ground water is not known. Further south, in the Petaluma Valley study area, the Meacham Hill fault is believed to act as a ground water barrier, based on ground water level data.

Soils

Soil is a product of many factors:

- The geologic formation that underlies it and from which it formed.
- The slope of the land.
- Age of the soil.
- Climate, especially the amount of rainfall.
- Organisms, especially native vegetation.

Of these factors, geologic material of origin is the most important. For example, the sandy soils in the vicinity of Sebastopol formed from the Merced Formation, which is composed predominantly of sandstone. The heavy adobe soils in the vicinity of Rohnert Park formed from basin deposits, which are largely clay. The steepness of the slope generally affects the thickness of the soil. On flat, or more stable, slopes the soil profile has had a longer time to develop than have the soils on steeper slopes where mass wasting and surface erosion occur more frequently. Age of the soil, organic material, and the amount of rainfall control the degree of development of the soil profile. Young soils, especially in arid climates, have relatively little profile development. Organisms modify soil characteristics such as the amount of nitrogen and organic matter in the soil.

In turn, soil characteristics control the types of crops that can be grown in an area, the amount of surface water that infiltrates to the ground water body, and the effectiveness of septic-tank leach-field sewage disposal systems. Agricultural crops usually grow best on deep, permeable soils. Some nearly impermeable adobe soils are suitable only for pasture. Permeable soils are necessary for recharge of surface water to the ground water body. Soils that have neither a very high infiltration rate (rate faster than 2 minutes per centimetre or 5 minutes per inch) nor a low infiltration rate (rate slower than 25 minutes per centimetre or 60 minutes per inch) are necessary for leach-field siting (Ford, 1975).

In general, in the Santa Rosa Plain, permeable soils have formed in creekbeds (on the alluvial deposits labeled Qal on Plate 1), at the heads of alluvial fans (Qf) where coarser materials are more common, on some units in the Sonoma Volcanics (Tsv), and on some portions of the Merced Formation (Tm). Soils with low permeability generally form on basin deposits (Qb), on the outer edges of alluvial fans (Qf) where the finest grained material has been deposited, on some units in the Sonoma Volcanics (Tsv), on some portions of the Petaluma Formation (Tp), and on the Franciscan complex (KJf).

In this report, only soils with an infiltration rate greater than 1.5 centimetres (0.6 inch) per hour and a land slope of less than 15 percent are considered to be permeable enough to allow significant recharge to ground water. These criteria were developed by the U. S. Geological Survey during recharge studies in the Santa Cruz area (Muir and Johnson, 1979). Approximately 10 percent of the study area has been tentatively classified as recharge areas. Locations of the recharge areas are discussed in Chapter 5.

CHAPTER 4. GROUND WATER USE AND SUPPLY IN THE SANTA ROSA PLAIN

Ground water supplies can be estimated once the geologic and hydrologic characteristics of a basin are understood. In the Santa Rosa Plain, the volume of ground water is controlled by the thickness of the water-yielding alluvial fan deposits and Merced Formation. The movement of ground water in the Santa Rosa Plain is reduced across the Sebastopol fault.

As of spring 1980, the study area contained 4 823 000 dam^3 (3,910,000 ac-ft) of ground water in water-yielding materials that average 120 m (400 ft) in thickness. If water level declines are to be controlled, long-term annual extractions from the ground water reservoir should not exceed the average annual recharge to the reservoir. The recharge is estimated at 36 100 dam^3 (29,300 ac-ft) annually from 1960 to 1975. The average yearly volume of ground water pumpage in the Santa Rosa Plain during the model period, 1960 through 1975, was estimated to be 36 600 dam^3 (29,700 ac-ft).

Method of Investigation Using TRANSCAP

In the Santa Rosa Plain, the TRANSCAP (transmissivity and storage capacity) computer program was used to determine:

- Total storage capacity.
- Volume of ground water in storage.
- Volume of storage capacity available to store recharge.

A detailed description of the TRANSCAP computer program is given in Miyazaki (1980).

The initial step in using TRANSCAP to study an area is to divide the area into "cells". In the Santa Rosa Plain, each cell is equivalent to a 260-hectare (640-acre) section, or a 130-hectare (320-acre) half-section. Figures 7 and 18 show study area and cell boundaries. Where the surficial geology is composed mainly of the Franciscan complex, cells were not evaluated because this complex is nonwater-yielding. Where the surficial geology is composed mainly of Sonoma Volcanics, cells were not evaluated because volcanic rocks are highly variable in their hydrologic properties.

Water well drillers' reports were collected for each cell to be evaluated. A sample well driller's report is shown in Figure 8. The right-hand column of the report lists the geologic materials encountered during drilling of the well. The materials in each well are then coded as to specific yield. This specific yield information is the basic data used by the TRANSCAP program.

The TRANSCAP program adjusts all wells within a cell to the average elevation of the land surface in that cell. The program then averages all specific yield data from all wells in a cell for specified depth intervals, generally 3 m (10 ft). The averaged specific yield data are converted to transmissivities using equations of a curve developed by the DWR investigation of the Livermore and Sunol Valleys (Ford and Hills, 1974). For specific yield values from 0 to 9, the curve is described by the equation:

$$\Delta T = \Delta D\ (10)^{x};$$

$$\text{where } x = \left[3.5319 - \frac{7.16288}{(SY - 0.84)} \right]$$

EXPLANATION

AVAILABLE STORAGE CAPACITY - SPRING 1980

1200 (1000) — AVAILABLE STORAGE CAPACITY IN CUBIC DEKAMETRES (ACRE-FEET)

19 — CELL NUMBER

AVAILABLE STORAGE CAPACITY NOT CALCULATED
IF 1) NONWATER-YIELDING FRANCISCAN COMPLEX
2) COMPOSED OF SONOMA VOLCANICS WITH HIGHLY VARIABLE WATER-YIELDING CHARACTERISTICS.

NATURAL RECHARGE AREAS

RECHARGE AREA (SOIL INFILTRATION RATE GREATER THAN 1.5 cm/HR, SLOPE LESS THAN 15%)

POTENTIAL RECHARGE AREA (IF SLOPE DOES NOT EXCEED 15%)

SLOW RECHARGE AREA (SOIL INFILTRATION RATE LESS THAN 1.5 cm/HR, OR SLOPE GREATER THAN 15%)

RECHARGE AREAS DETERMINED USING U.S. SOIL CONSERVATION SURVEY MAPS (Miller 1972), AFTER Muir AND Johnson (1979)

FIGURE 7

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

AVAILABLE STORAGE CAPACITY PER CELL AND AREAS OF NATURAL RECHARGE

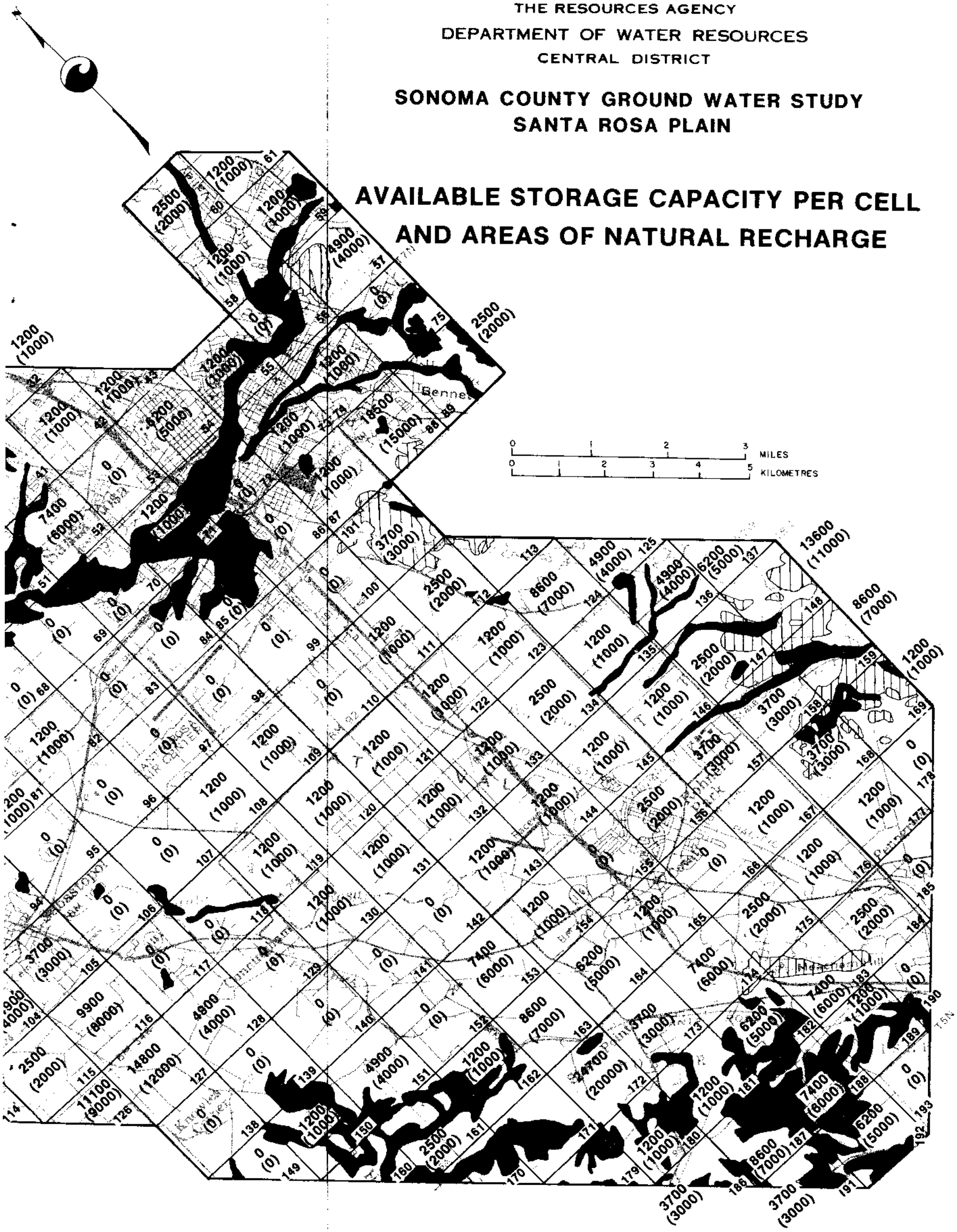


FIGURE 8

ORIGINAL
File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
WATER WELL DRILLERS REPORT

Do not fill in

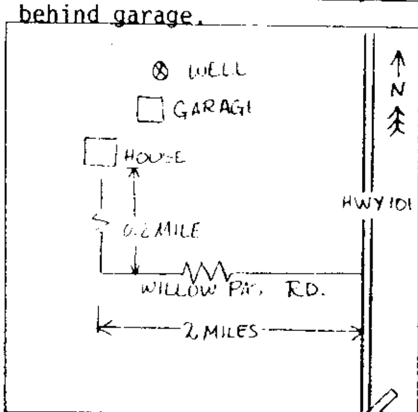
No. SAMPLE

Notice of Intent No. ____
Local Permit No. or Date ____

State Well No. ____
Other Well No. ____

(1) OWNER: Name Alice Mar
Address 212 South Willow Pass Road
City Woodlake, California Zip 93563

(2) LOCATION OF WELL (See instructions):
County Sonoma Owner's Well Number 74-2
Well address if different from above ____
Township 7N Range 6W Section 19
Distance from cities, roads, railroads, fences, etc. 4 miles west of Woodlake, 2 miles east of Highway 101, 0.2 mi. north of Willow Pass Road, NE of house behind garage.



WELL LOCATION SKETCH

(3) TYPE OF WORK:
New Well ☒ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic ☒
Irrigation ☐
Industrial ☐
Test Well ☐
Stock ☐
Municipal ☐
Other ☐

(5) EQUIPMENT:
Rotary ☒ Reverse ☐
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:
Yes ☒ No ☐ Size 1/8-1/4"
Diameter of bore 12"
Packed from ____ to ____ ft.

(7) CASING INSTALLED:
Steel ☒ Plastic ☐ Concrete ☐

From ft.	To ft.	Dia. in.	Gage or Wall
0	152	8"	1/4"

(8) PERFORATIONS:
Type of perforation or size of screen ____

From ft.	To ft.	Slot size
40	51	100
129	143	

(9) WELL SEAL:
Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 50 ft.
Were strata sealed against pollution? Yes ☐ No ☒ Interval ____ ft.
Method of sealing Cement Grout

(10) WATER LEVELS:
Depth of first water, if known 23 ft.
Standing level after well completion 28 ft.

(11) WELL TESTS:
Was well test made? Yes ☒ No ☐ If yes, by whom? A-OK Drilling
Type of test Pump ☐ Bailer ☐ Air lift ☐
Depth to water at start of test 23 ft. At end of test 37 ft.
Discharge 100 gal/min after 24 hours Water temperature 67°F
Chemical analysis made? Yes ☒ No ☐ If yes, by whom? Dow Lab
Was electric log made? Yes ☒ No ☐ If yes, attach copy to this report

(12) WELL LOG: Total depth ____ ft. Depth of completed well ____ ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	4	top soil
4	23	brown sandy loam
23	40	brown clay and gravel
40	41	coarse sand and pebble gravel
51	68	brown sandy with minor clay
68	92	blue sand
92	97	coarse sand with shell fragments
97	103	sand and pebble gravel with minor clay
103	125	red volcanic rock
125	129	black crystal vitric tuff
129	143	andesite
143	147	dark grey volcanic ash
147	152	scoria and volcanic ash
152	165	fractured andesite

Work started 16 June 1959 Completed 21 June 1959

WELL DRILLER'S STATEMENT:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED Seymour Rocks
(Well Driller)

NAME A-OK Drilling Co.
(Person, firm, or corporation) (Typed or printed)

Address 2664 So. Bascomb
City Woodlake, CA Zip 93563
License No. 000001 Date of this report 20 July 1959

DWR 188 (REV. 7-76)

SAMPLE WATER WELL DRILLERS REPORT

and for specific yield values greater than 9, the curve is described by the equation:

$$\Delta T = \Delta D\ [100\ (SY) - 500]$$

Where ΔT = incremental transmissivity (gallons/day/ft);

ΔD = incremental depth (ft); and

(SY) = percent value for average specific yield for a given interval.

When no drillers' logs were available for a cell, transmissivity and storage capacity values from another cell with similar geology were used.

A sample TRANSCAP printout in customary units is shown on Figure 9. The variables listed in the upper left-hand corner of the table describe the values used to set up TRANSCAP for this cell. Increment of Depth = 10 indicates that specific yields were averaged over 10-ft (3-m) intervals. Node Elevation Control is the average elevation of the land surface within the cell. Node Surface Area is the surface area, in acres, of the cell. Note that the center point in a cell is called the "node".

The figure describes hydrologic properties by intervals: either as "Depth" below land surface or "Elevation" relative to sea level. For example, for the interval from 10 to 20 ft (3 to 6 m) above sea level or 80 to 90 ft (24 to 27 m) below land surface, the "average specific yield" is 10.30 percent, the "unit width transmissivity" is 5,300 gallons/day (20 000 litres/day) and the "storage capacity" is 673 ac-ft (830 dam^3). These computer-generated numbers are rounded to one or two significant figures before use, to avoid giving an erroneous impression of precision.

To determine the storage capacity of any cell, the bottom of the water-yielding zone must first be determined. The graph in Figure 9 entitled "unit width summation of transmissivity plot" shows a profile of the transmissivity in the sample cell. Points on the graph represent unit width transmissivity values that have been summed starting at the lowest elevation evaluated for the cell. Summed unit width transmissivity values in gallons per day are listed in the right-hand column labeled "TR VALUE" opposite the corresponding elevation. The numbers across the top of the graph are summed unit width transmissivities in thousands of gallons per day.

The point at the lowest elevation on the graph represents 0. As elevation increases, the points on the graph move from left to right, and the heading is read from left to right, lowest line first (0 to 500).

If the summed transmissivities exceeded 500 thousand gallons per day, the graph would double back, and the headings would then read from right to left (500 to 1,000). When the summed transmissivities exceeded 1,000 thousand gallons per day, the graph would again double back and the headings read from left to right (1,000 to 1,500).

The more horizontal the line on the graph, the more permeable the water-yielding zone. The more vertical the line, the more that zone functions as a confining bed. The bottom of the water-yielding zone is determined from the TRANSCAP graph and is verified by comparison with geologic maps and cross sections. The top of the water-yielding zone is generally assumed to be the land surface. The net storage capacity of the water-yielding zone is calculated by subtracting the "storage capacity to bottom" figure at the bottom of the water-yielding zone from the corresponding figure at the top of the water-yielding zone.

The program TRANSCAP calculates storage capacities to the bottom of the deepest well in each cell. No storage capacity information is available for that portion of an aquifer below the bottom of the deepest well. For cells where the aquifer extends below the well data, the storage capacity from TRANSCAP is a minimum value; the true storage capacity would be higher.

In the Santa Rosa Plain, the thickness of the water-yielding materials ranges from 15 to 310 m (50 to 1,010 ft), with an average thickness of 120 m (400 ft).

To determine the volume of water in storage, the average ground water level for the cell is determined from a ground water level map. The volume of water in storage is determined by subtracting the "storage capacity to bottom" figure at the bottom of the water-yielding zone from the corresponding figure at the ground water table elevation.

Water level information for spring 1980 (Figure 10) was combined with the product of TRANSCAP to determine the storage capacity, the total volume of water in storage, and the available ground water storage capacity in the Santa Rosa Plain. Available storage capacity indicates the capability of the cell to store additional ground water from natural or artificial recharge. Figure 7 presents available storage capacity (estimated for cells where no drillers' logs were available). Figure 11 shows the volume of ground water in storage per cell.

Use of the Basin

In an area with a rapidly growing population, such as the Santa Rosa Plain, increases in the demand for water must be anticipated so that adequate supplies will be available when needed. Data on past population growth and ground water pumpage can be used to predict, to some extent, future demand on the ground water reservoir, provided the centers of growth remain similar. The amount of ground water currently in storage in the reservoir can be used to estimate the amount of ground water available for extraction in the future.

During the model period, extending from fall 1960 through spring 1975, a total of 549 200 dam^3 (445,300 ac-ft) of ground water was extracted from the basin. The pumped water was used as follows:

- Agricultural -- 322 900 dam^3 (261,800 ac-ft)
- Rural-Domestic -- 133 000 dam^3 (107,800 ac-ft)
- Industrial -- 47 700 dam^3 (38,700 ac-ft)
- Municipal -- 45 600 dam^3 (37,000 ac-ft)

Average yearly pumpage during the model period was 36 600 dam^3 (29,700 ac-ft). The population of the valley in 1975 was approximately 114,400, of which 50,600 depended on ground water for their water supply. Of the 50,600 residents in 1975, an urban population of 19,600 and a rural population of 31,000 depended on ground water.

The largest single user of ground water in Sonoma County is the City of Rohnert Park. From July 1980 to June 1981, Rohnert Park pumped 4 900 dam^3 (4,000 ac-ft) of ground water. During the same period, Sebastopol pumped 1 349 dam^3 (1,012 ac-ft) of ground water, Sonoma State University pumped 378 dam^3 (307 ac-ft), and Cotati pumped 290 dam^3 (235 ac-ft). While the total amount of ground water pumped for agricultural use is larger than that pumped for any other use (rural domestic, industrial, or municipal), agricultural use represents many individual pumpers and not a single entity. The municipalities, however, pump from their own wells, generally located within the relatively restrictive area of their city or property limits, whereas wells for other users are distributed throughout Santa Rosa Plain.

Records show that the amount of ground water being extracted for municipal use is increasing each year. Ground water

FIGURE 9

NODE 7

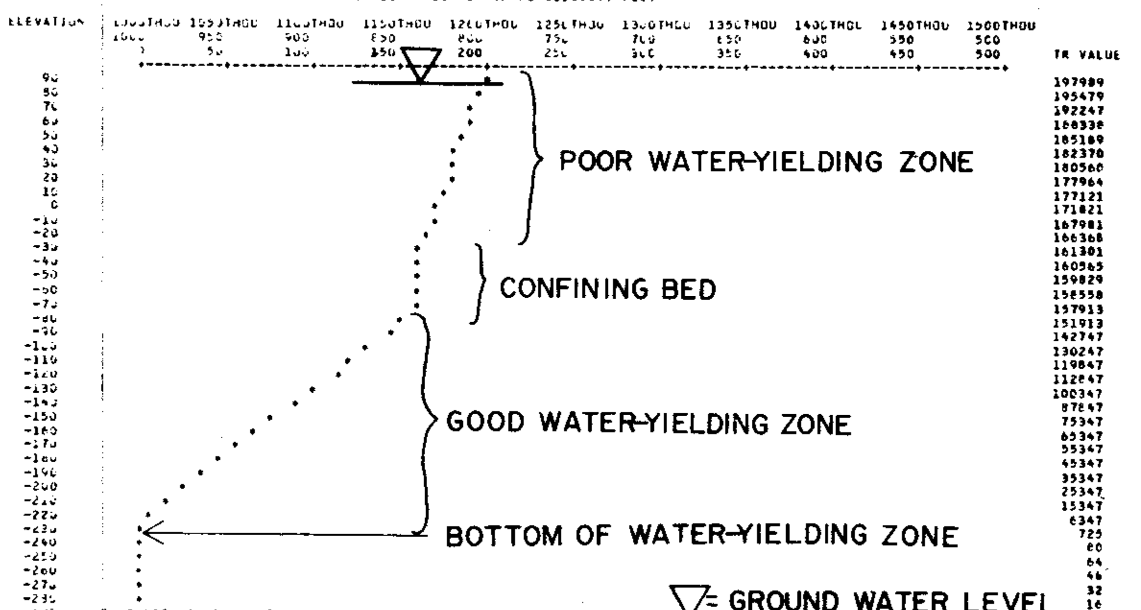
SONOMA COUNTY
GROUND WATER INVESTIGATION
DEPTH INCREMENT CALCULATIONS FROM SPECIFIC YIELD

PAGE 1
DATE 10/27/81

INCREMENT OF DEPTH = 10
NODE ELEVATION CONTROL = 100
NODE SURFACE AREA (ACRES) = 654
SY VALUE FOR CLAY = 3

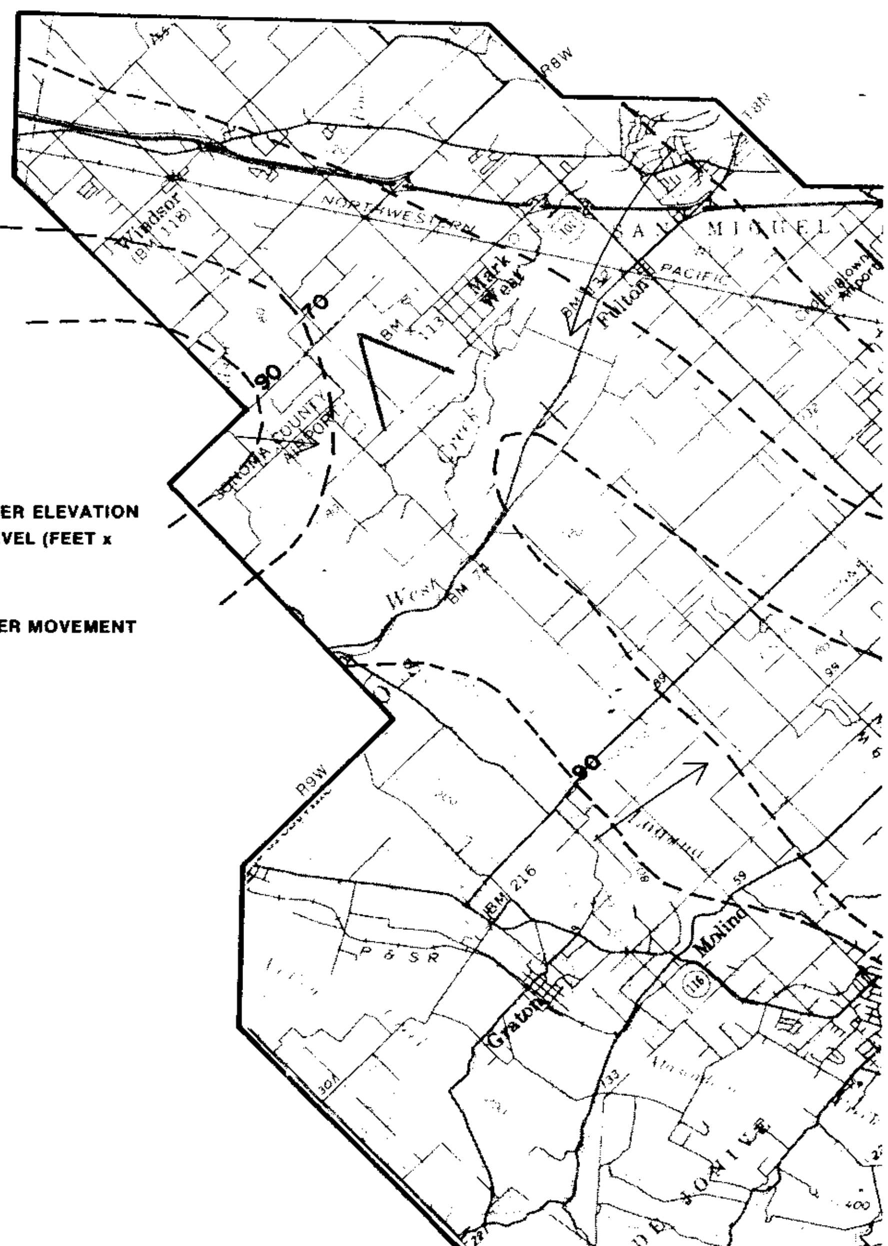
DEPTH	ELEVATION	AVERAGE SPECIFIC YIELD (IN PERCENT)	UNIT WIDTH TRANSMISSIVITY (GAL/DAY)	UNIT WIDTH TR FOR USE IN MODEL AC-FT/YR	STORAGE CAPACITY (ACRE-FEET)	STORAGE CAPACITY TO BOTTOM (ACRE-FEET)	NO. OF SAMPLES
10	90	7.17	25[illegible]0	221	468	24178	12
20	80	7.85	3232	219	513	80 23710	13
30	70	6.46	3409	215	553	23197	13
40	60	7.77	3149	211	508	22644	13
50	50	7.46	2619	207	487	22136	13
60	40	6.46	1020	204	422	21649	13
70	30	7.25	2596	202	474	21227	12
80	20	5.30	843	199	346	20753	10
90	$\boxed{10}$	$\boxed{10.30}$	$\boxed{5330}$	198	$\boxed{673}$	20407	10
100	0	6.45	354[illegible]	192	549	19734	10
110	-10	6.25	1613	189	405	19185	8
120	-20	9.50	5067	186	621	18777	8
130	-30	5.14	736	180	336	18156	7
140	-40	5.14	736	179	336	17820	7
150	-50	5.86	1271	179	393	17484	7
160	-60	5.00	645	177	327	17101	6
170	-70	11.00	6000	177	719	16774	6
180	-80	14.17	9166	170	926	16055	6
190	-90	17.50	12500	160	1144	15129	6
200	-100	15.40	10400	146	1007	13985	5
210	-110	12.00	7000	134	784	12978	4
220	-120	17.50	12500	126	1144	12194	2
230	-130	17.50	12500	112	1144	11050	2
240	-140	17.50	12500	96	1144	9906	2
250	-150	15.00	10000	84	981	8762	1
250	-160	15.00	10000	73	981	7781	1
270	-170	15.00	10000	62	981	6800	1
280	-180	15.00	10000	50	981	5819	1
290	-190	15.00	10000	39	981	4838	1
300	-200	15.00	10000	28	981	3857	1
310	-210	14.00	9000	17	915	2876	1
320	-220	10.00	3522	7	654	1961	1
330	-230	5.00	645	0	327	1307	1
340	-240	3.00	16	0	196	980	1
350	-250	3.00	16	0	196	784	1
360	-260	3.00	16	0	196	588	1
370	-270	3.00	16	0	196	392	1
380	-280	3.00	16	0	196	196	1

UNIT WIDTH SUMMATION OF TRANSMISSIVITY PLOT



AVERAGE SPECIFIC YIELD = 9.73

SAMPLE TRANSCAP PRINTOUT



EXPLANATION

- 50 — — APPROXIMATE GROUND WATER ELEVATION IN FEET RELATIVE TO SEA LEVEL (FEET x 0.3048 = METRES)

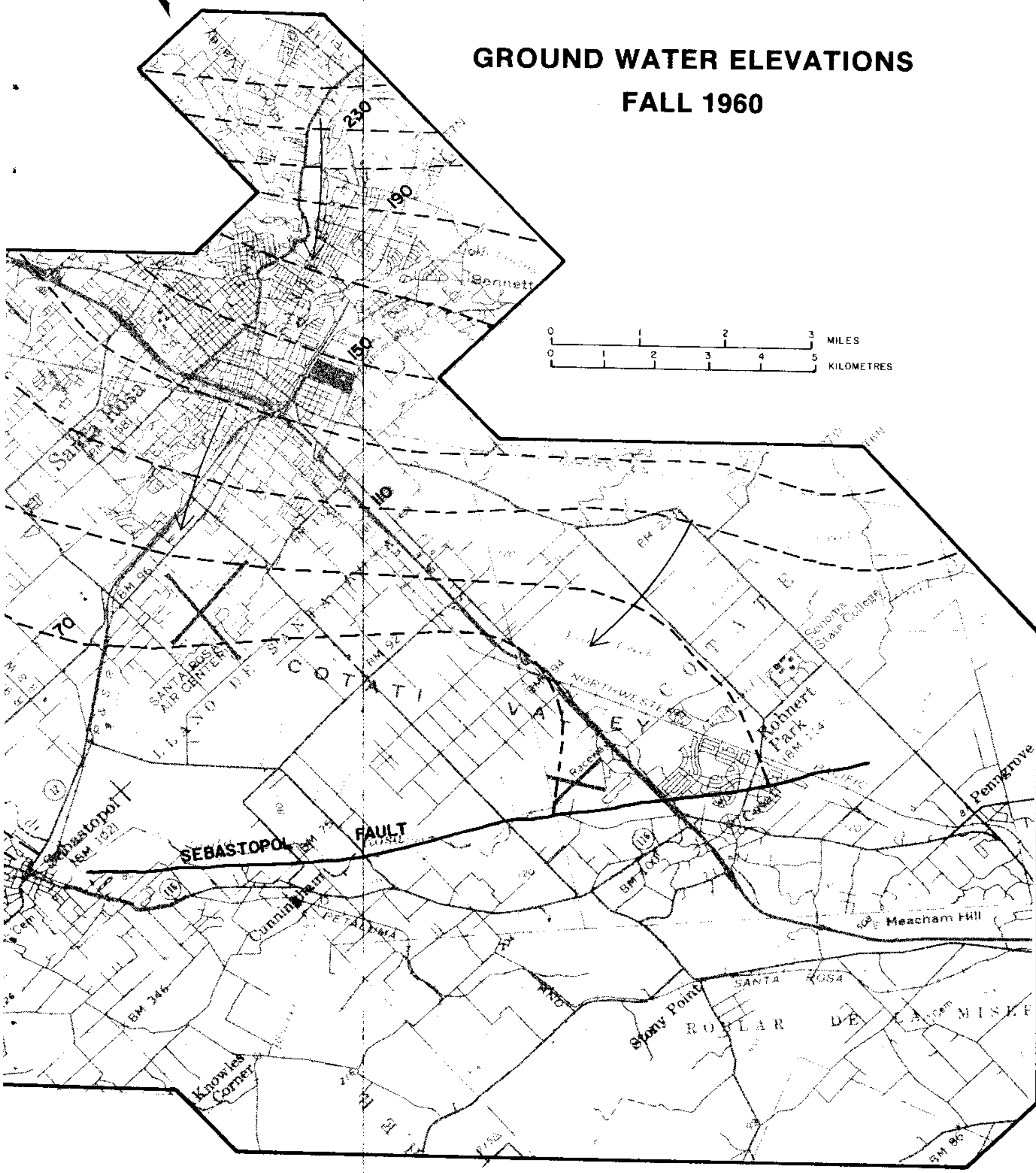
———> DIRECTION OF GROUND WATER MOVEMENT

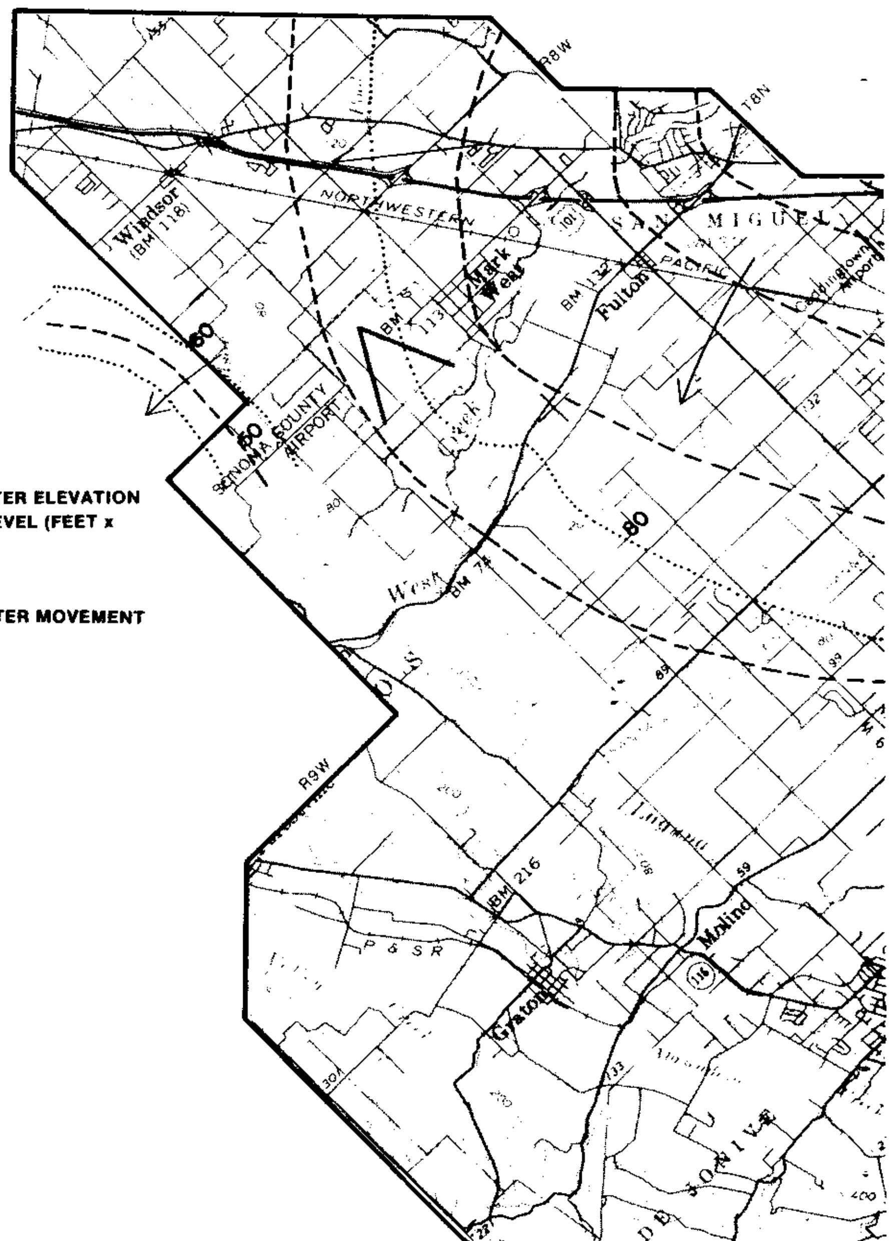
FIGURE 10 A

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

GROUND WATER ELEVATIONS
FALL 1960





EXPLANATION

— — — 50 — — — APPROXIMATE GROUND WATER ELEVATION IN FEET RELATIVE TO SEA LEVEL (FEET x 0.3048 = METRES)

DIRECTION OF GROUND WATER MOVEMENT

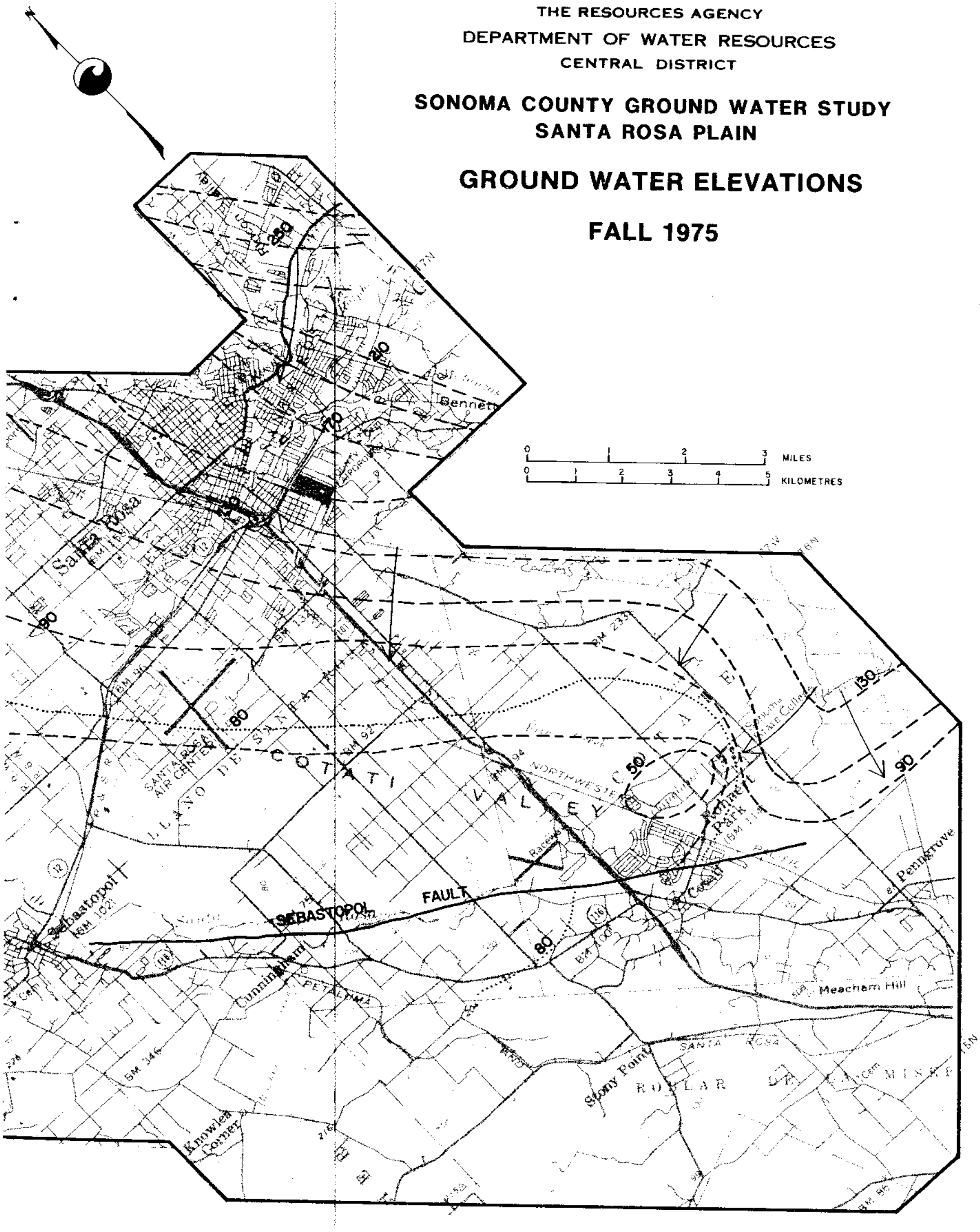
FIGURE 10 B

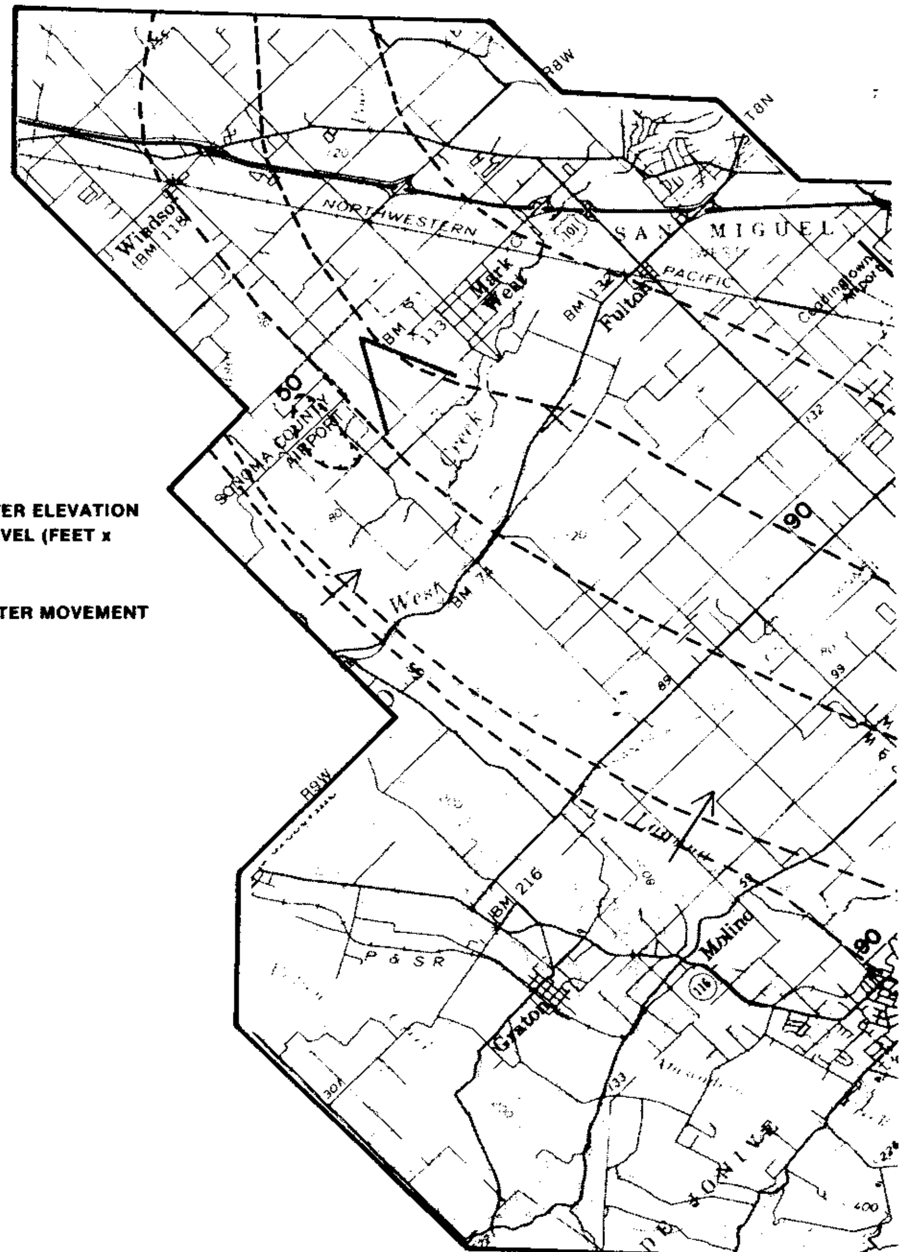
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

GROUND WATER ELEVATIONS

FALL 1975





EXPLANATION

— — 50 — — APPROXIMATE GROUND WATER ELEVATION IN FEET RELATIVE TO SEA LEVEL (FEET x 0.3048 = METRES)

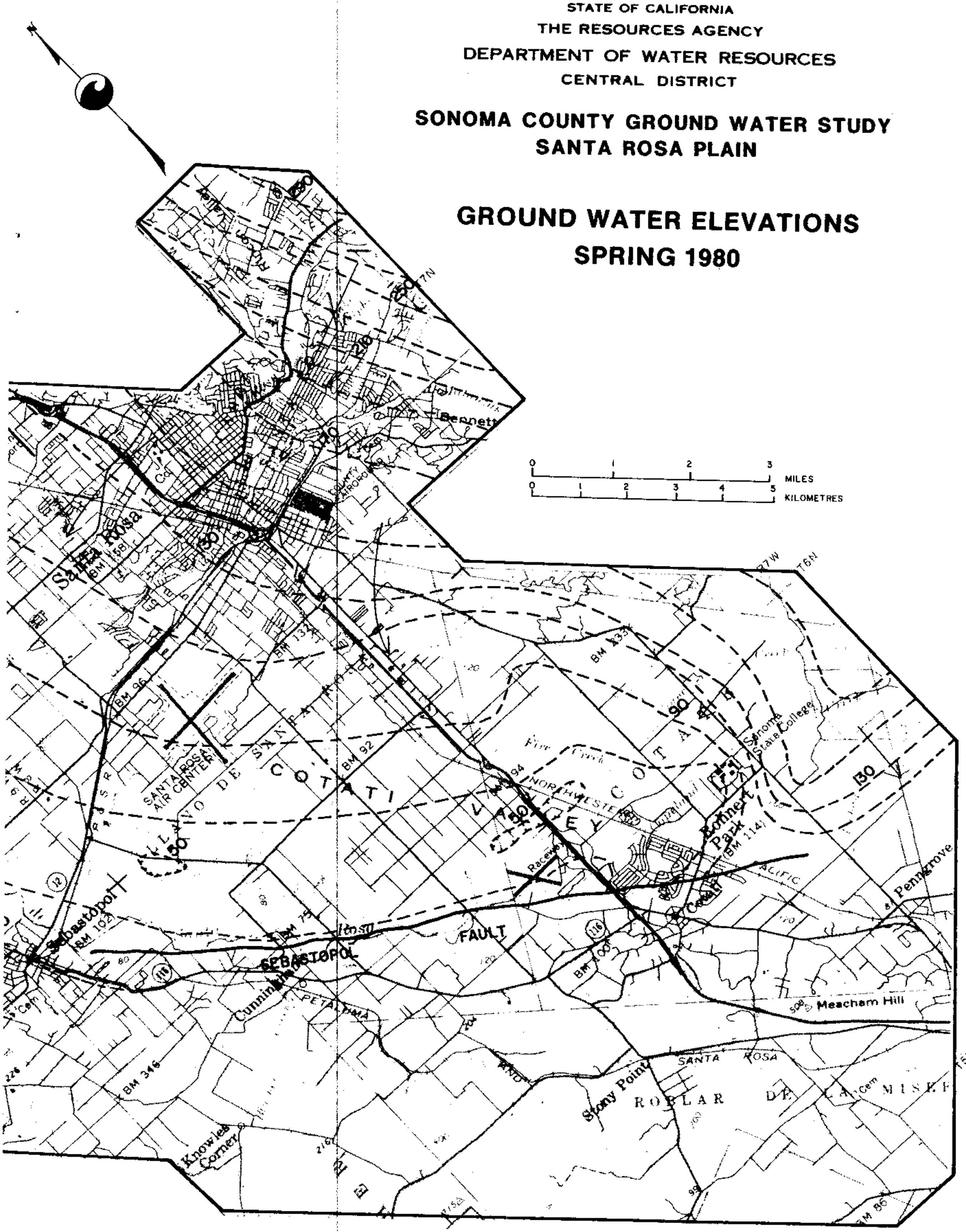
⟶ DIRECTION OF GROUND WATER MOVEMENT

FIGURE 10 C

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

GROUND WATER ELEVATIONS
SPRING 1980



EXPLANATION

GROUND WATER IN STORAGE — SPRING 1980

1200
(1000)

GROUND WATER IN STORAGE IN CUBIC DEKAMETRES (ACRE-FEET)

19

CELL NUMBER

GROUND WATER IN STORAGE NOT CALUCLATED IF AREA

1) COMPOSED OF NONWATER-YIELDING FRANCISCAN COMPLEX
2) COMPOSED OF SONOMA VOLCANICS WITH HIGHLY VARIABLE WATER YIELDING CHARACTERISTICS

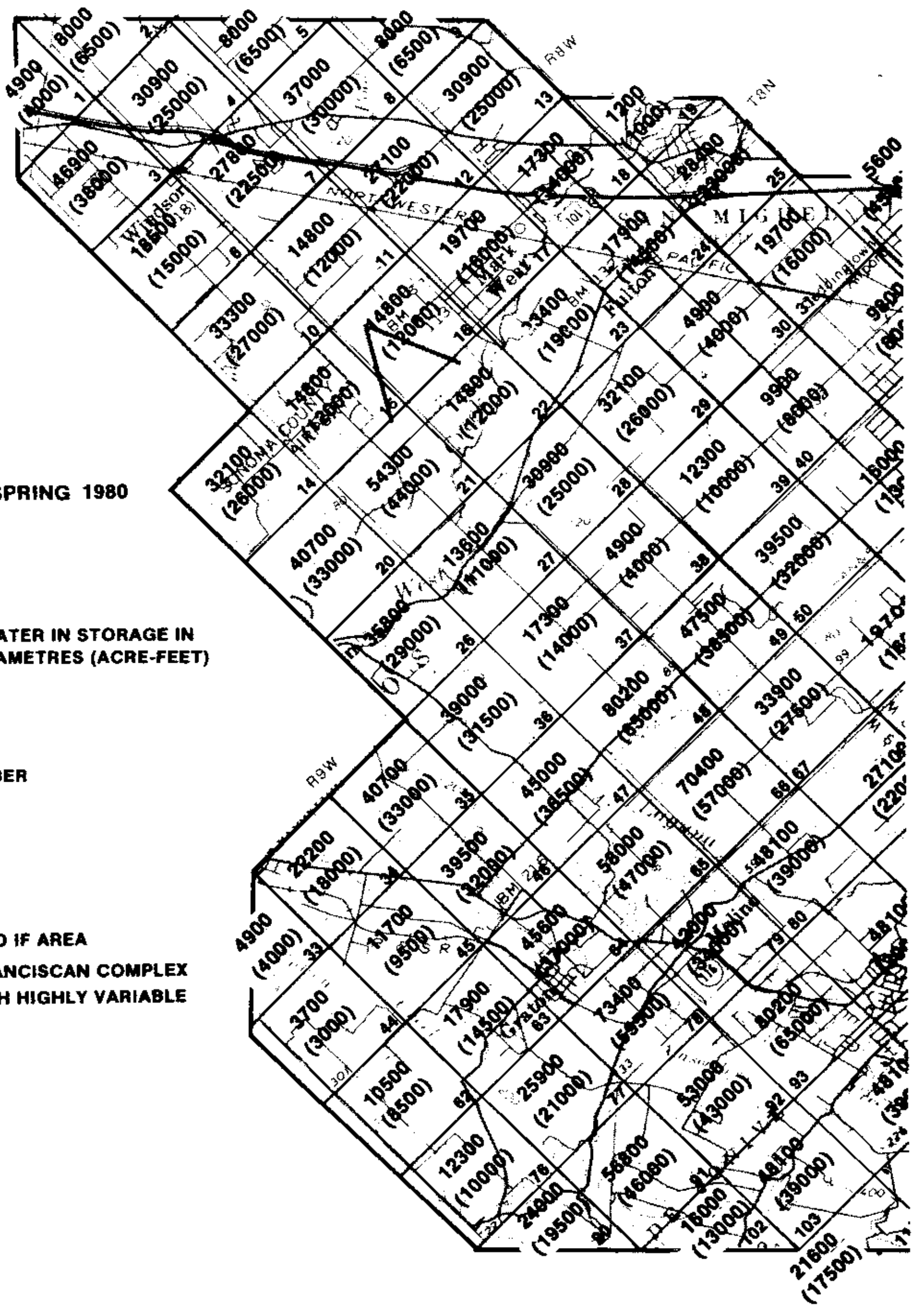
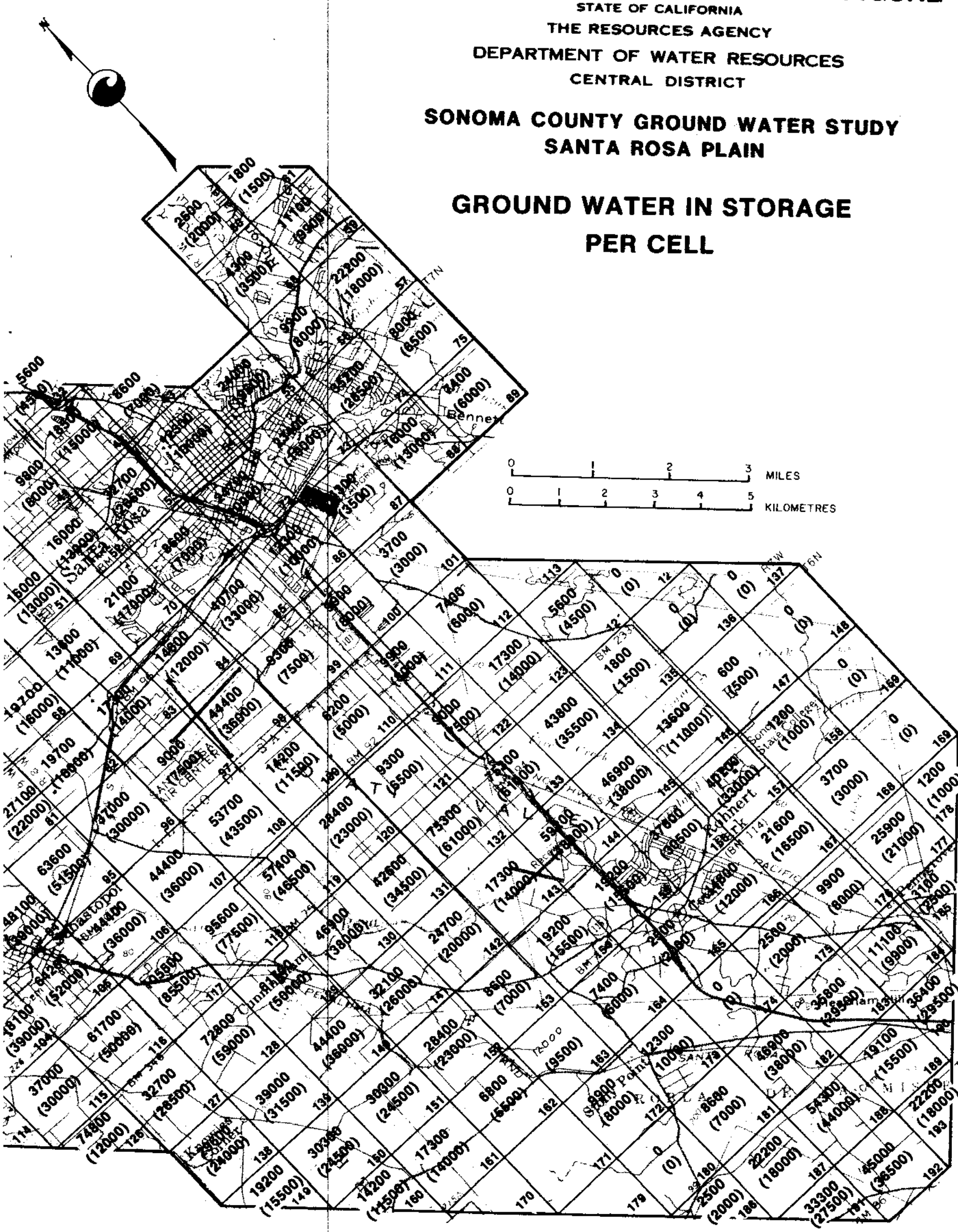


FIGURE 11

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

GROUND WATER IN STORAGE PER CELL



levels rise after municipal pumpage is reduced in autumn, and they usually have not completely recovered when pumpage resumes in spring. Successive ground water elevation measurements showing little, if any, change would indicate a stabilized supply and demand of ground water. Of 18 municipal water wells in Rohnert Park, 12 showed declines in spring measurements over a period of years until fall 1981, while six showed rises. Measurements taken in spring 1982 showed that water levels in 14 of the 18 wells rose significantly, apparently in response to the high winter rainfall of that year and the subsequent decreased demand for applied water. Three piezometers in well 6N/8W-23A2, 3, and 4 (Figure 12) have also risen, probably for the same reasons.

The fast rise of the water levels in deeper wells after high rainfall and the corresponding reduction in applied water demands of the 1981-82 winter indicates that some wells may be measuring a localized pressure surface. The several different water levels under Rohnert Park probably indicate that water is being extracted from different confined or semiconfined aquifers, and these are probably recharged on the alluvial fans of the eastern foothills (Figure 7).

Total Water in Storage and Available Storage Capacity

Table 2 gives an estimate of the total volume of ground water in storage and the available ground water storage capacity in Santa Rosa Plain and is based on the assumption that ground water in Santa Rosa Plain as a whole is unconfined. These estimates do not include four cells in remote parts of the study area for which no subsurface data are available.

Under natural conditions the ground water reservoir was saturated. Because some of the strata in the reservoir are less permeable than others, water confined below the less permeable strata was under artesian pressure. If measured, water levels in such aquifers would have risen somewhat above the less permeable strata. When water is withdrawn from a confined or semiconfined aquifer, the difference between the water level measured in that aquifer and others will usually continue and may increase, depending on the amount of water withdrawn from each aquifer over a given time. Once the withdrawal of water from confined or semiconfined aquifers stops, the measured water level recovers fairly quickly.

Between 1960 and 1975, ground water levels in Santa Rosa Plain (Figures 10A and 10B) rose, declined, or remained about the same in various parts of the Plain. Ground water levels rose about 3 m (10 ft) near Santa Rosa, where use of ground water decreased. This amounts to a rise of about 0.2 m (0.7 ft) per year for that 15-year period. Ground water in this area appears to have stabilized at these higher levels (Figure 10C).

In southern Santa Rosa Plain, where the rate of ground water extraction has been increasing, ground water contours indicate that water levels have declined as much as 12.2 m (40 ft) during the same period (Figures 10A and 10B), amounting to a maximum decline of about 0.8 m (2.7 ft) per year. Between 1975 and 1980, the pumping depression has apparently migrated slightly westward (Figure 10C).

In 1977, piezometers were built in a well in Rohnert Park to measure ground water levels at 65, 95, and 195 m (214, 312, and 640 ft), called "red", "white", and

TABLE 2

GROUND WATER SUPPLY IN THE SANTA ROSA PLAIN

Total Storage Capacity	5 320 000 dam³ (4,313,000 ac-ft)
Amount of Ground Water in Storage (Spring 1980)	4 823 000 dam³ (3,910,000 ac-ft)
Storage Capacity Available to Accept Recharge (Spring 1980)	497 000 dam³ (403,000 ac-ft)

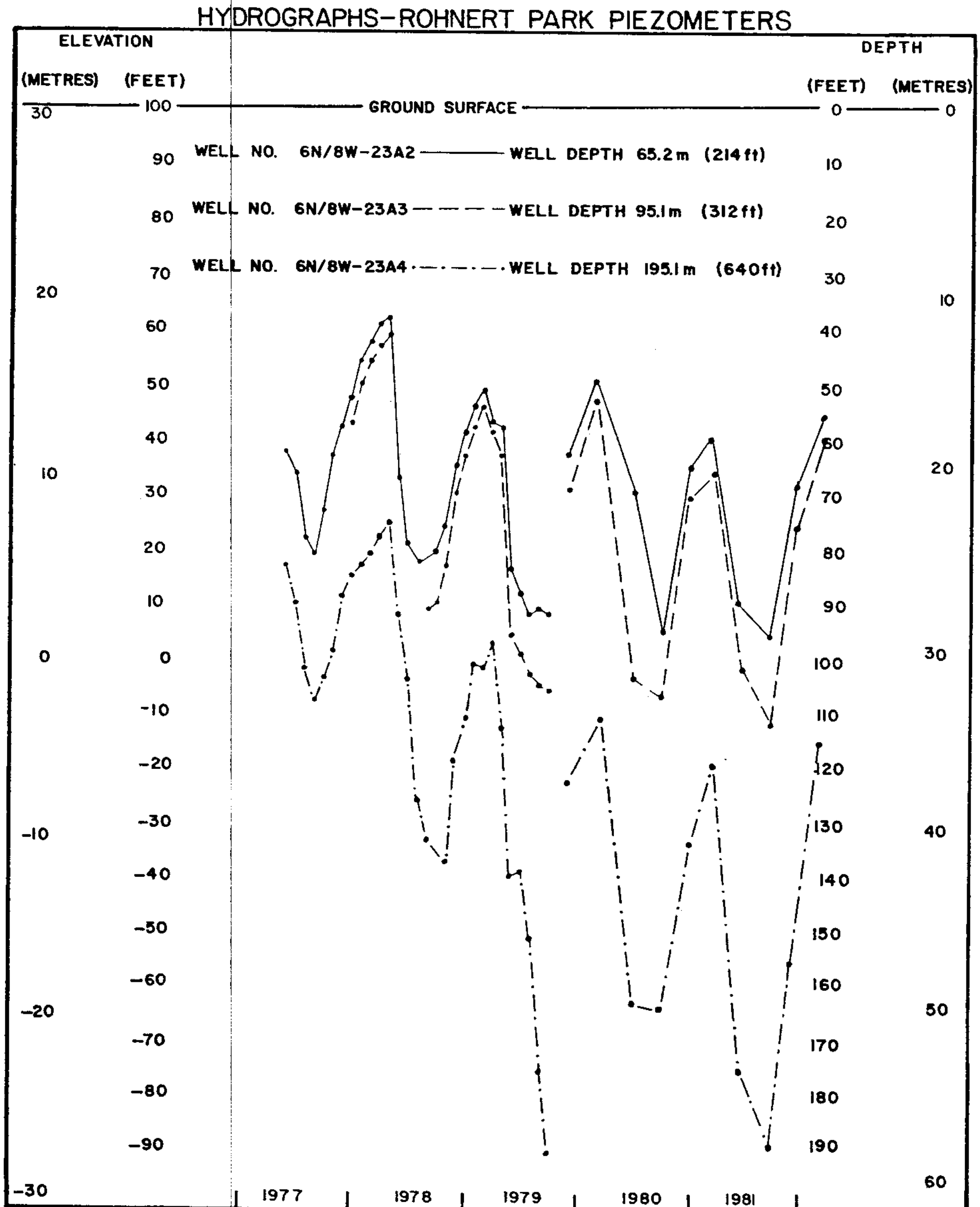

HYDROGRAPHS-ROHNERT PARK PIEZOMETERS
ELEVATION
(METRES) (FEET)
DEPTH
(FEET) (METRES)
GROUND SURFACE
WELL NO. 6N/8W-23A2 WELL DEPTH 65.2m (214ft)
WELL NO. 6N/8W-23A3 WELL DEPTH 95.1m (312ft)
WELL NO. 6N/8W-23A4 WELL DEPTH 195.1m (640ft)
1977
1978
1979
1980
1981

FIGURE 12

"blue", respectively (6N/8W-23A2, 3, and 4). When measurements of the three piezometers began in 1977, the difference between water levels in the shallower tubes (65 and 95 m (214 and 312 ft)) and the deep tube (195 m (640 ft)) totaled about 6 m (20 ft) (see Figure 12). Between 1977 and 1980, the water level in all three piezometers declined, and the difference between the shallow tubes and the deep tube increased to almost 18.3 m (60 ft).

The water levels in the two shallow piezometers declined from 6.1 m to 7.6 m (20 to 25 ft), or about 1.7 m (5.5 ft) per year from 1977 to 1981. The water level in the deep piezometer declined from 13.7 to 16.8 m (45 to 55 ft), or about 3.8 m (12.5 ft) per year over the same period. This deeper piezometer is at a depth similar to most of the Rohnert Park municipal water wells. The differences in water levels among the three tubes indicate that there are restrictive layers between the perforations in each of the piezometers. Such differences in water levels are typical of pressure aquifers from which ground water is being or has been withdrawn.

In early 1982, water levels in all three piezometers had risen above the previous year's highest water level measurement, apparently in response to the high rainfall of the 1981-82 winter and the subsequent decrease in demand for water. Because the winter's rainfall was significantly higher than average, such rapid recovery of the ground water levels should not be considered to be a long-term trend. It is probable that the downward trend of the ground water levels will continue unless wetter winters become common.

Ground water level measurements from 1977 to 1981 in the majority of Rohnert Park's 18 municipal water wells show rates of decline similar to those of the piezometers, while water levels in some of the wells show a rise. Water level decline ranged from 9 to 15.2 m (30 to 50 ft) and rises ranged from 3 to 8.8 m (10 to 29 ft) in individual wells. The average change in spring measurements was -1.5 m (-5 ft) per year; median change was -1.5 m (-5 ft) per year. The average change in fall measurements was -4.3 m (-14 ft) per year; median change was -3.3 m (-10.7 ft) per year. Such rates of change warrant monitoring by ground water users in the area. The Department of Water Resources, Sonoma County Water Agency, and most of the cities conduct such a ground water monitoring program.

The rainfall of winter 1981-1982 was so much greater than normal that water levels in many wells rose considerably. By early 1982, spring water levels in 14 out of 18 of Rohnert Park's wells had risen from 0.3 m (1 ft) to as much as 13.1 m (43 ft) above levels of the previous spring. The average increase between 1981 and 1982 spring measurements was 6.4 m (21 ft). In the four wells where spring water levels declined, the declines ranged from 2.4 m (8 ft) to 4.3 m (14 ft) for the year, and averaged about 3.0 m (10 ft).

As with the piezometers, such increases are apparently the result of the abnormally high rainfall of winter 1981-1982 and should not be considered to be a long-term trend unless the higher rainfall continues for a number of years. These facts should be considered in evaluating water level trends.

During the time that ground water levels in southern Santa Rosa Plain were declining, ground water levels near Santa Rosa were rising. These differences tend to counter each other so that the basin, when viewed as a whole, can be considered essentially in balance. Details about the geologic and hydrologic continuity between the two areas are not available. Increasing pumpage in Santa Rosa Plain may reduce the volume of water in storage to a level below that of spring 1980, the period used for calculations presented in this report.

The estimate of available storage capacity given in Table 2 indicates that the Santa Rosa Plain basin is 9 percent dewatered. If this dewatered storage were distributed evenly throughout the basin, the effect on ground water levels would be small. This is not the case, however, and stable or rising levels are, in general, offset by the pumping depression in the south. Smaller depressions are located east of Sebastopol and several miles northwest of Santa Rosa (Figures 10A-C). Further dewatering of storage capacity can locally increase recharge if the available storage is created near a natural or artificial recharge area.

Estimated Annual Recharge

The volume of stream percolation in the Santa Rosa Plain ground water reservoir between 1960 and 1975 has been estimated at 273 100 dam^3 (221,400 ac-ft) and the volume of percolation from rainfall and applied water has been estimated at 268 700 dam^3 (217,800 ac-ft) for a total volume of recharge of 541 800 dam^3 (439,200 ac-ft). The average annual recharge from 1960 to 1975 has been estimated at 36 100 dam^3 (29,300 ac-ft). Long-term extractions from the ground water reservoir should not exceed long-term recharge if permanent depletion of the ground water in storage is to be avoided.

CHAPTER 5. GROUND WATER MOVEMENT IN THE SANTA ROSA PLAIN

Movement of ground water in Santa Rosa Plain, like ground water everywhere, is governed by the hydraulic gradient and the physical characteristics of the ground water reservoir. The amount of such movement is directly proportional to the hydraulic gradient, the hydraulic conductivity, and the cross-sectional area of the saturated material through which the water is moving. The continuity of the aquifers plays a significant role in governing the movement of ground water from one area to another. Aquifer continuity also influences the movement of naturally and artificially recharged water from a recharge site to an area of ground water extraction.

Aquifer Continuity

The degree of aquifer continuity is controlled by two factors: the influence of faults on ground water and the areal extent of each single aquifer or group of interconnected aquifers. Faults influence ground water by reducing transmissivity across the fault plane; the influence of faults on ground water movement can be determined from constant-rate pump tests of water wells and from ground water level maps.

The areal extent of an aquifer or aquifers can be evaluated by examining the surficial and subsurface geology, reviewing ground water quality data to locate similar quality types, and comparing hydrographs for wells of different depth or in different locations.

The geology of the Santa Rosa Plain ground water reservoir is extremely complex. Some geologic units in the Santa Rosa Plain contain water-yielding sands and gravels in discontinuous lenses; other units do not contain water-yielding materials. In addition, the ground water reservoir is divided by northwest-trending faults, which reduce the thickness of water-yielding materials on the upthrown side of the fault; the Sebastopol fault is known to reduce transmissivity across its trace.

These conditions result in a number of partially separated ground water bodies of differing characteristics. These same conditions also affect the potential for vertical and horizontal movement of ground water. Ground water movement can be analyzed for local areas within the Santa Rosa Plain, but because of the number of separated subbasins, some of which may be semiconfined, generalities or predictions of ground water behavior and mineral content based on existing data are of questionable value.

To determine if a fault impedes ground water flow, a 24-hour constant-rate pump test of a water well near the fault can be used. An abrupt drop in the apparent transmissivity of the aquifer will appear when the pumping cone of the well intercepts a fault acting as a barrier, or any other impedance to flow. The only pump test available for a well in the Santa Rosa Plain near a suspected barrier is a test of the Todd Road emergency well (6N/8W-7A2). This test indicated that the Sebastopol fault impedes ground water movement because no drawdown was reported in a nearby well of similar depth on the opposite side of the fault.

Two other methods to determine aquifer continuity were used in this study. Ground water quality data were examined to determine areas of either different or similar water quality in:

° Shallow zones -- to elevation -30 m (-100 ft)

- ° Intermediate zones -- elevation -30 to -70 m (-100 to -200 ft)
- ° Deep zones -- elevation greater than -70 m (-200 ft)

Hydrographs for shallow and deep wells in the same area were examined to determine how closely the pattern of fluctuations in the ground water levels match.

Zones of ground water have been denoted by their elevation relative to sea level in order to make comparisons. In general, the elevation of the valley floor is between 20 to 60 m (60 to 200 ft). The mountains bordering the study area on the west have a maximum elevation of 160 m (520 ft); the mountains bordering the eastern edge, 365 m (1,200 ft). In general, a well denoted as shallow is less than 45 m (150 ft) deep; one denoted as deep generally exceeds 105 m (350 ft) deep.

To determine the areal extent of the various aquifers in the Santa Rosa Plain, standard mineral analyses of ground water were evaluated. Standard mineral analyses include the concentrations of the cations calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), and potassium (K^{+}), and the anions bicarbonate (HCO_3^{-}), carbonate ($CO_3^{=}$), sulfate ($SO_4^{=}$), and chloride (Cl^{-}).

In this report, water types are described by listing cations first, in order of abundance in milliequivalents per litre, followed by anions, in order of abundance. A single cation or anion is used to describe a water type if that ion constitutes over 50 percent of the total cations or anions in solution. Closely spaced wells with similar water quality types were assumed to tap the same aquifer. Conversely, aquifer separation exists to the degree that water quality types vary when taken from wells at different locations but with perforations at the same elevation or from wells at different elevations at the same location.

Ideally, ground water quality data collected entirely within a single year in a developing area such as Santa Rosa Plain should be used to evaluate regional water quality because the chemical composition of ground water can change as the result of development. Water quality data for the Santa Rosa Plain are sparse and were collected sporadically over 30 years. Analyses were available for 85 private wells and for 35 municipal wells belonging to the cities of Santa Rosa, Rohnert Park, Sebastopol, Cotati, and the Sonoma County Water Agency. In some cases, several analyses have been collected for the same well. In determining ground water quality patterns, the most recent data have been given the most weight. In the area of Windsor, however, a series of 1951 analyses depict a distinctive magnesium sodium chloride bicarbonate water. Although this water quality data is old, the area has been delineated on the water quality map and should be verified by additional water samples.

Based on the sparse available data, mostly pre-1960, water quality types generally correspond to a particular geologic formation. The Merced Formation beneath the valley floor generally produces a sodium bicarbonate water.

Few data are available on the quality of water from the Sonoma Volcanics, and the unit consists of many different rock types, each of which influences water quality differently. In general, ground water from the Sonoma Volcanics appears to be a sodium calcium magnesium bicarbonate.

Alluvial fan deposits generally produce a magnesium calcium bicarbonate water, but there are many variations. Sodium is present in some locations in the fan deposits. As with the Sonoma Volcanics, variation is due to the variety of geologic materials in the fans (clay, sand, and gravel deposited from different sources).

The basin deposits generally produce a calcium magnesium sodium bicarbonate water; the presence of calcium as a dominant cation is characteristic of water from the basin deposits.

Sufficient data are not available to characterize water from the Petaluma Formation or the Franciscan complex in the Santa Rosa Plain. In Department of Water Resources Bulletin 118-4, Volume 1 (Ford, 1975), water from the Petaluma Formation was described as a sodium bicarbonate to a sodium or calcium chloride. Water from the Franciscan complex was described as sodium bicarbonate in that report based on a single available analysis.

Figure 13 shows the distribution of ground water quality types within the valley. Good vertical aquifer continuity appears to exist on the western side of the study area, northwest of Santa Rosa. Sodium and bicarbonate are the dominant cation and anion in water from all depths. Moving south along the western side of the valley, the extent of hydraulic separation between the shallow and deep aquifers appears to increase. The shallow waters have magnesium and calcium as the dominant cations; below -46 m (-150 ft), sodium is the dominant cation. In the vicinity of Windsor, there appears to be little vertical continuity between water in the shallow zone (with dominant cations calcium and magnesium) and water in the deep zone (dominantly sodium). Areas with apparent good vertical aquifer continuity are northwest and northeast of Santa Rosa, where water from all depths is magnesium bicarbonate and sodium bicarbonate, respectively.

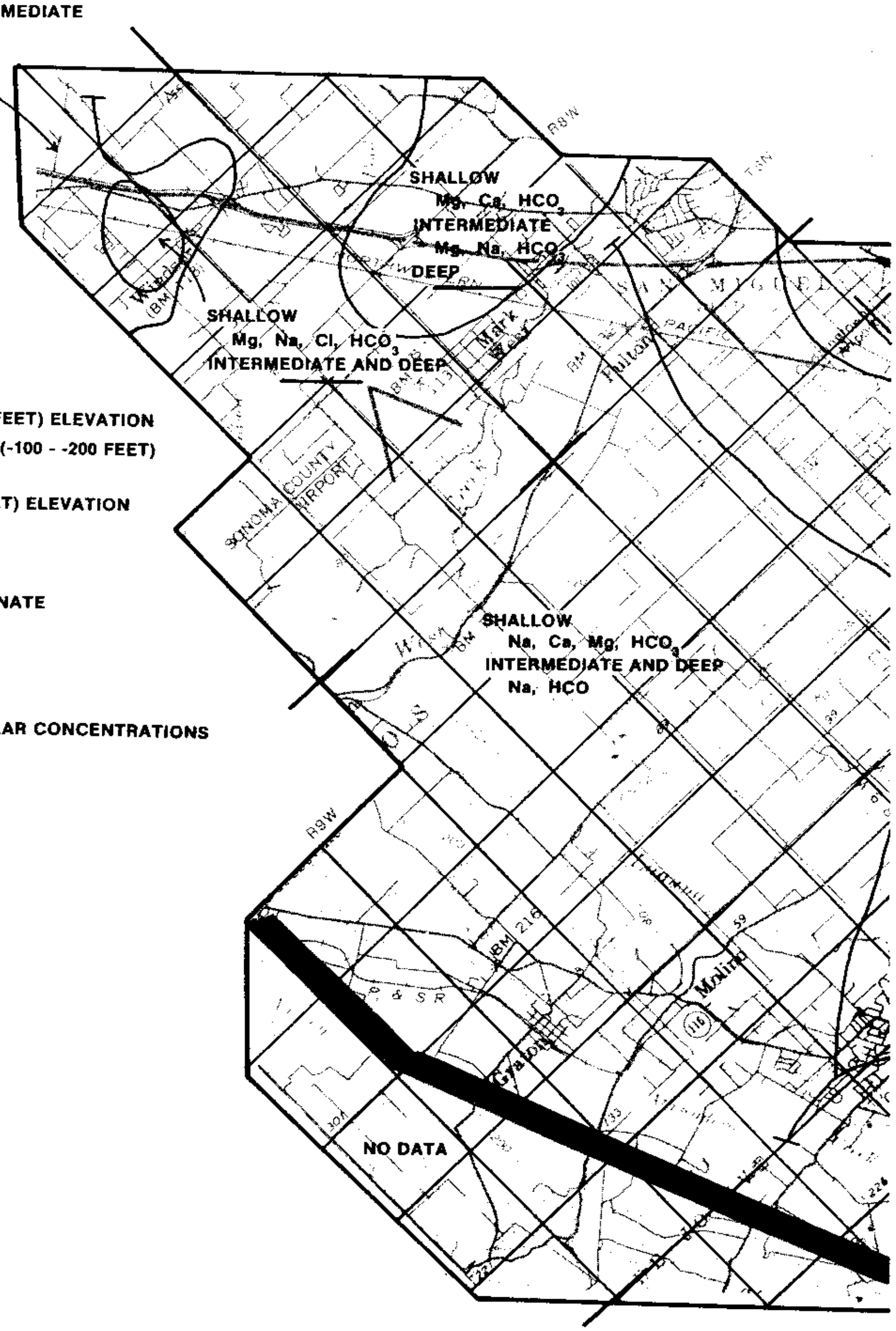
The cause of horizontal separation of aquifers of similar depths in the study area is not well understood. Water-yielding sands and gravels may not have been originally deposited as continuous sheets or stringers, or originally continuous aquifer materials may have been offset by faults. Sufficient data are not available to evaluate the causes of horizontal separation of aquifers in the Santa Rosa Plain. Separation appears to exist between the northwestern and northeastern portions of the valley, and between the deep wells south of Santa Rosa and near Rohnert Park. In the area extending from Wilfred south to Rohnert Park, there is a high degree of variation in water quality, both vertically and horizontally. This may be due to compartmentalization of aquifers in the area, or to ion exchange between deep clay layers and ground water. During an ion exchange process, the concentration of sodium in the ground water is increased and the concentration of calcium and magnesium is decreased (Hem, 1959). Shallow ground water near Windsor contains magnesium and chloride as the dominant cation and anion, in contrast to other nearby shallow aquifers containing mostly calcium or sodium bicarbonate water. The unusual quality changes may be due to a local perched water table that is not connected with nearby shallow water-yielding zones.

Thirty-one hydrographs for wells in the Santa Rosa Plain were paired (nearby deep and shallow wells) and examined for similar response to stress and recharge. The similarities and differences in responses between pairs correlate with predictions of aquifer connection, or lack of connection, based on water quality data. In one case, hydrographs reveal continuity between deep and shallow aquifers in an area where no shallow water quality data are available: between well 6N/8W-15R1 (313 m or 1,028 ft deep) and well 6N/8W-15J3 (51 m or 166 ft deep) (see Figure 14).

Sea Water Intrusion

There is no evidence of sea water intrusion in Santa Rosa Plain, although it has occurred in Petaluma Valley to the south.

Movement of sea water into the Santa Rosa Plain is restricted by the ground water divide that separates it from the Petaluma Valley. Little research has been done on the nature of this divide. It may be related to the Adobe Creek



EXPLANATION

SHALLOW AQUIFER = -1 TO -30 METRES (-100 FEET) ELEVATION
INTERMEDIATE AQUIFER = -30 TO -60 METRES (-100 - -200 FEET) ELEVATION
DEEP AQUIFER = BELOW -60 METRES (-200 FEET) ELEVATION

CATIONS	ANIONS
Na - SODIUM	HCO_3 - BICARBONATE
Ca - CALCIUM	Cl - CHLORIDE
Mg - MAGNESIUM	

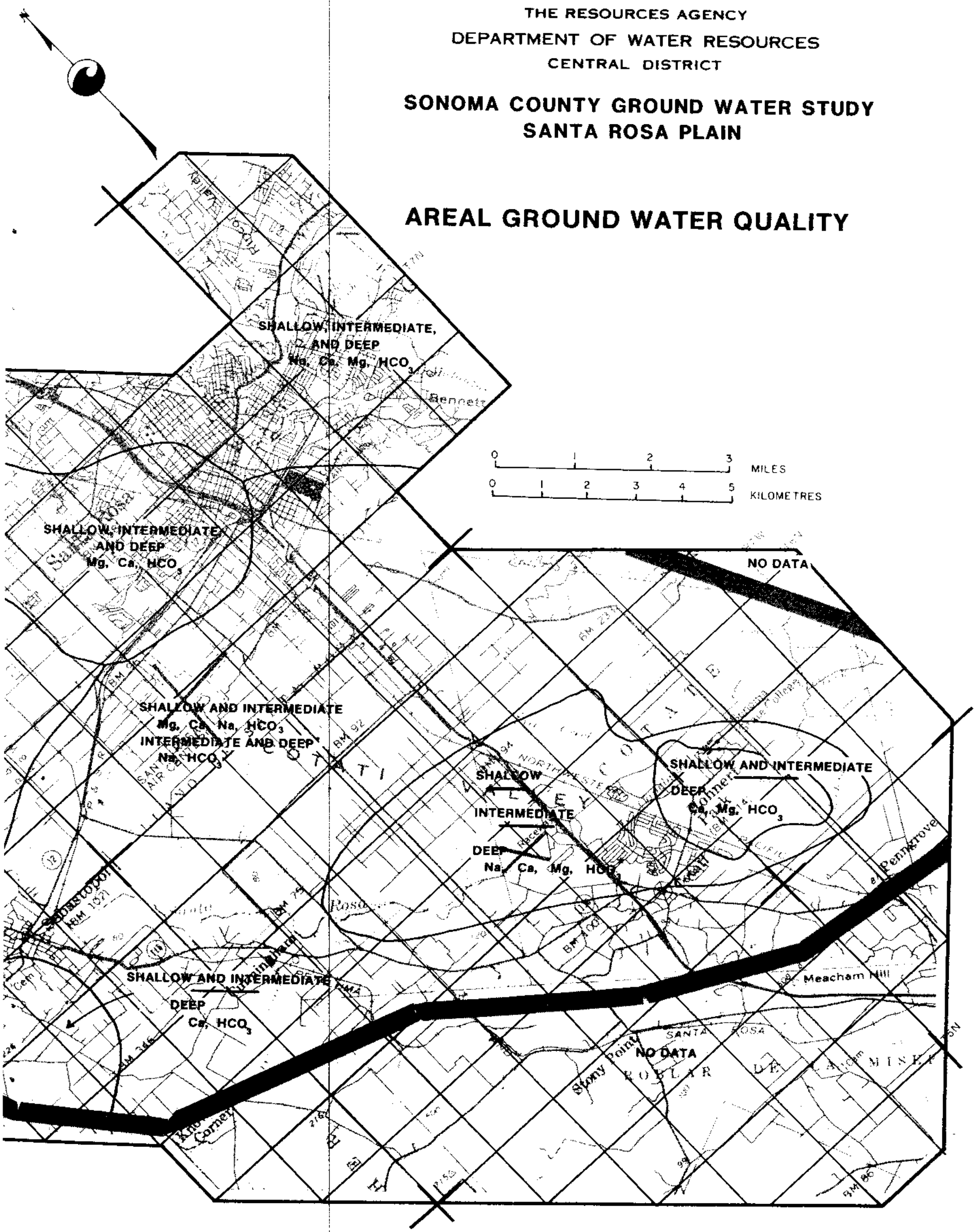
* ALL THREE CATIONS PRESENT IN SIMILAR CONCENTRATIONS
"——" INDICATES NO DATA AVAILABLE

FIGURE 13

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

AREAL GROUND WATER QUALITY



HYDROGRAPHS

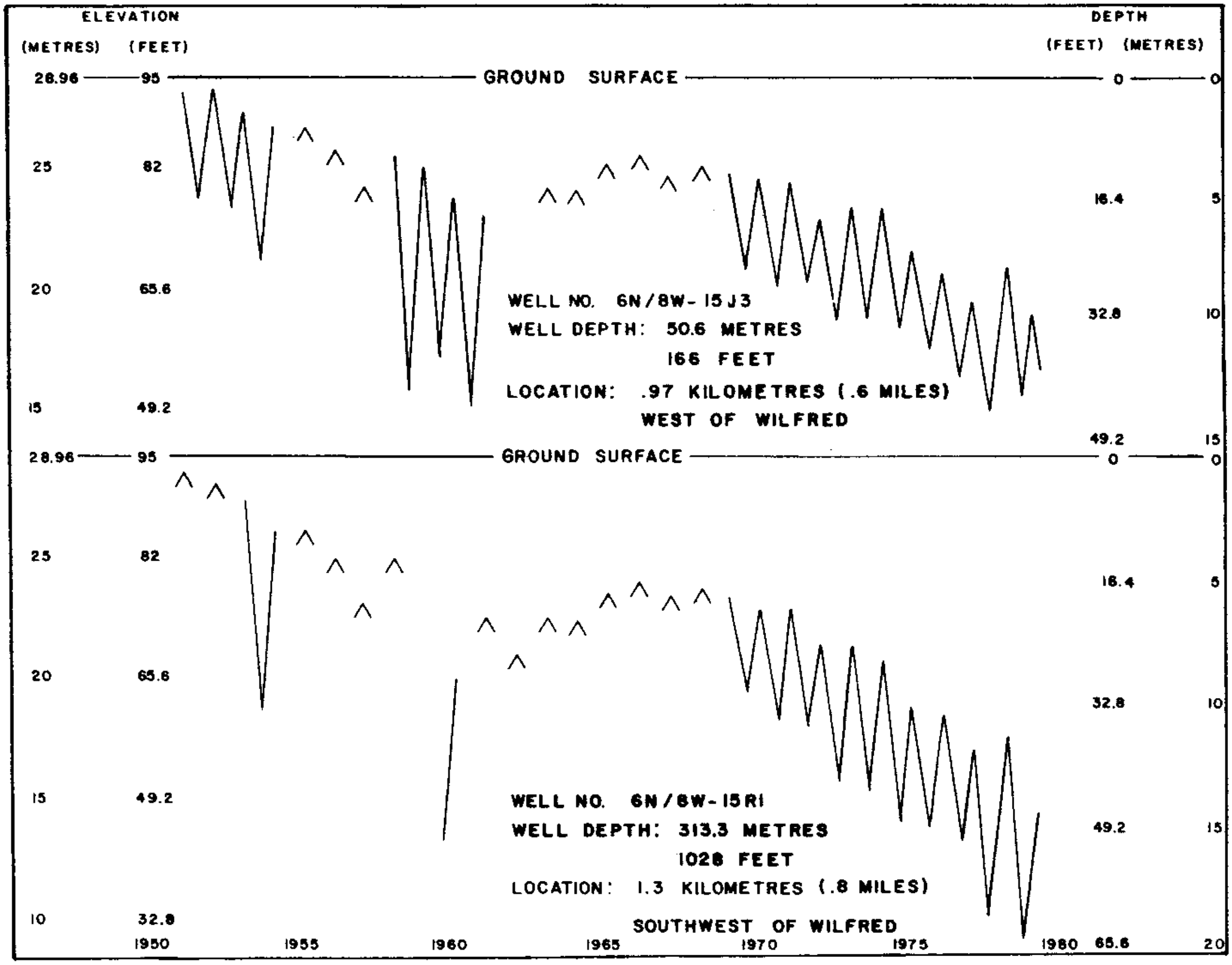


FIGURE 14

Anticline, an upward warp in the Petaluma Formation; this formation underlies the hills on the east side of the Petaluma Valley. If an anticlinal structure is the cause of the divide, it is unlikely that sea water could move up through the formation and over the divide into the Santa Rosa Plain. In addition, the distance of Santa Rosa Plain from a source of sea water in San Pablo Bay makes it unlikely that such intrusion will occur.

Effect on the Russian River and Tributaries from Increased Ground Water Extraction

There are not enough data to make a quantitative estimate of the connection between surface water and ground water in the Santa Rosa Plain. The streambeds of Santa Rosa, Mark West, Windsor, Matanzas, Spring, and Rincon Creeks are sufficiently permeable to be recharge areas (see following section). At the present time, there is little available storage for ground water in the aquifers beneath these creeks, so the infiltration of surface water to the ground water body is probably small. If ground water extraction in these areas were to increase, thereby creating additional available storage space, the infiltration of surface water would increase proportionately.

The degree to which increased pumping in areas away from the creeks will affect available storage in the aquifers beneath the creeks is variable. It depends on the degree of aquifer connection between the two areas and on the presence or absence of barriers, such as faults.

There are no stream gaging stations operating in the Santa Rosa Plain; gaging stations are maintained only on the Russian River. Because of the lack of gaging stations, there is no way to accurately determine the amount of surface water that infiltrates to the ground water body. Stations would have to be installed at appropriate creeks in the Santa Rosa Plain to determine the volume of ground water recharge.

In general, there are few similarities between surface and ground water quality in the Santa Rosa Plain. This appears to indicate a lack of connection between surface and ground water. An exception is water from Santa Rosa Creek at the Laguna de Santa Rosa, which is a sodium magnesium bicarbonate similar in quality to shallow ground water in the area, which is a sodium calcium magnesium bicarbonate. Surface water in other areas appears to be a mixture of quality types, and no correlation is apparent (Table 3).

In 1958, the U. S. Geological Survey reported that water levels in creeks in the Santa Rosa Plain and Petaluma Valley generally stood lower than the water levels in nearby wells, indicating that outflow of ground water was maintaining streamflows. There are not sufficient recent shallow ground water level data available to compare stream and ground water levels at the present time.

Natural and Artificial Recharge

Natural recharge is the movement of water from land surfaces and streambeds into underlying aquifers. Because most aquifers in the Santa Rosa Plain are full at present, recharge occurs in response to natural subsurface outflow or pumpage of ground water from those aquifers. Several physical factors affect the potential natural recharge rate in an area:

° Slope of the land surface.

° Permeability of the soils.

° Subsurface geology.

° The amount of available storage space in the aquifer.

An estimate of the annual volume of natural recharge is presented in Chapter 4.

For significant recharge to take place in an area, the slope of the land surface should be relatively low and the infiltration rate of the soil should be relatively high. Muir and Johnson (1979) state that recharge can occur when the slope is less than 15 percent and the infiltration rate of the soil is greater than 1.5 centimetre (0.6 inch) per hour. If the slope is greater than 15 percent, rapid runoff greatly reduces the recharge potential.

Subsurface geology is an important factor in evaluating a recharge area and is the most difficult factor to evaluate. Good aquifer continuity between the area of recharge and the area of extraction is necessary. The extent of aquifer continuity in the Santa Rosa Plain has already been discussed at the beginning of this chapter. The ground water level measurement network now being implemented by the Department of Water Resources and the Sonoma County Water Agency will provide more information on the continuity of aquifers. Other data that would aid in determining water movement would be:

° 24-hour constant-rate pump tests to determine aquifer transmissivity.

° Drilling at potential artificial recharge sites to determine detailed local subsurface geology.

The amount of storage space available in any aquifer at any location determines whether recharge can take place at that location. Without storage space available in the underlying aquifer, surface water will run off the most favorable recharge site as "rejected recharge". Figure 7 shows areas of favorable slope and soils within the study area and estimates of dewatered space available for storage as of spring 1980 in aquifers within each cell.

Soils with slopes and permeabilities suitable for natural and artificial recharge cover 5 300 hectares (13,200 acres) in the Santa Rosa Plain study area -- 9 percent of the total land surface (Figure 7). (Note: This 9 percent figure is different from the 9 percent available ground water storage capacity mentioned previously.) An additional 850 hectares (2,100 acres) are covered by soils of suitable permeability; they can be classified as recharge areas if the land slope is less than 15 percent.

The most significant natural recharge locations are the stream channels incised in alluvial fan deposits. Major natural recharge areas are along Mark West, Santa Rosa, Matanzas, Rincon, and Windsor creeks. At the present time, however, little storage for ground water is available in aquifers underlying these favorable areas. Many of the alluvial fan deposits in the Santa Rosa Plain are not permeable enough to act as recharge areas, although some slow infiltration of rainwater through fan deposits does take place. The adobe soils that have formed on basin deposits and soils that have formed on the clay-rich Petaluma Formation are generally not permeable enough to allow high rates of recharge (Plate 1).

Some recharge takes place on permeable soils overlying the Merced Formation in the southwestern portion of the study area. Many of the permeable soils that form on the Merced on the western portion of the study area are too steep for much recharge to take place. If runoff were controlled by modification of slopes, construction of ponds, or other methods, recharge to ground water could be increased.

Some recharge also takes place in sedimentary units of the Sonoma Volcanics (labeled Tsv on Plate 1). In general, however, slopes are too steep and permeabilities too low for much recharge to take place in the Sonoma Volcanics. Since aquifers in the Sonoma Volcanics are discontinuous, the rate and direction of movement of recharged water is difficult to determine.

In mountainous areas, recharge from rain or streams occurs where an aquifer is exposed at the surface. Recharged ground water then moves down dip in the aquifer (Figure 15) until:

° The water reaches the lowest point in elevation.

° The aquifer again is at the land surface, where ground water is released as a spring.

° Ground water encounters a barrier, which reduces the flow rate through the barrier.

When aquifers are as discontinuous as those in the mountainous portions of the study area, ground water frequently does not reach the area of ground water extraction because of these geologic complexities.

If further investigations in areas of more extensive ground water usage suggest that artificial recharge should be included in the water resources management plan, then it should be approached systematically, as in one study done for Sonoma County Water Agency.

In designing an artificial recharge program, care should be taken to ensure that the recharged water can reach the area of extraction. A detailed subsurface geologic investigation should be conducted for any proposed site, including on-site drilling and evaluation of the degree of connection between the recharge area and the area of extraction. If a surficial recharge program such as surface spreading of water is planned, the recharge site(s) selected should be in an area of favorable slope and soil infiltration rate.

TABLE 3

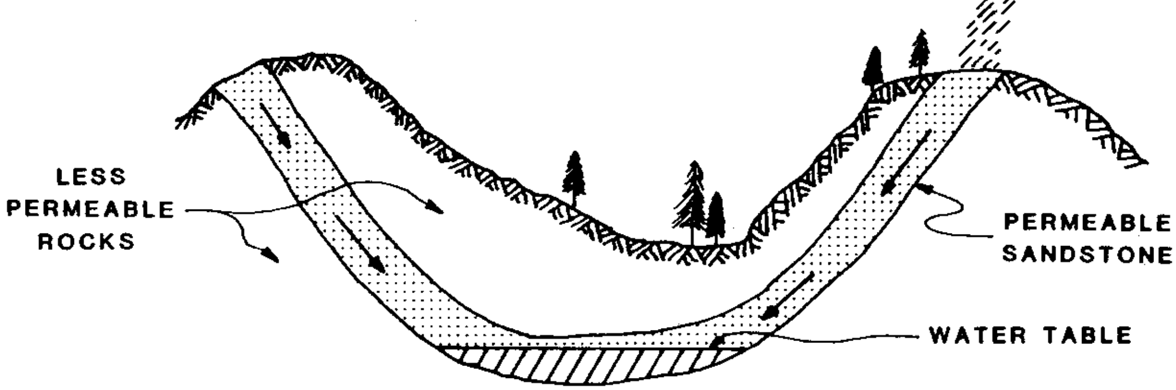
QUALITY OF SURFACE WATER IN THE SANTA ROSA PLAIN

Stream	Sampling Location	Date of Sampling (mo/yr)	Specific Conductance (μS/cm)	Total Hardness (mg/L)	Total Dissolved Solids (mg/L)	Principal Mineral Constituents (mg/L) Na^+	Ca^{++}	Mg^+	K^+	Cl^-	HCO_3^-	SO_4^{--}	CO_3^{--}	B	Fe	Mn	NO_3^-	Water Quality Type
Green Valley Creek	At Guerneville Hwy.	7/65	290	105	156	15	20	13	2.9	15	131	12	0	0.10	1.5	--	0.7	Magnesium Calcium
		7/66													1.1	0.84		Sodium Bicarbonate
Mark West Creek	At Trenton-Healdsburg Road	7/65	740	215	417	75	41	27	8.4	63	294	30	0	0.60	--	--	12.0	Sodium Magnesium
		7/66													1.5	0.70		Calcium Bicarbonate
	At Old Redwood	7/65	331	182	143	16	31	16	3.9	13	185	9.2	0	0.30	--	--	1.3	Calcium Magnesium
		7/66													0.04	0.07		Bicarbonate
Santa Rosa Creek	At Willowside	7/65	852	215	465	77	33	32	9.5	71	328	28	0	0.50	--	--	2.9	Sodium Manganese
		7/66													0.30	0.10		Bicarbonate
	At Montgomery Road Bridge	7/65	439	198	264	17	37	26	2.7	7.8	225	11	15	0.30	--	--	0.0	Magnesium Calcium
		7/66													0.32	0.11		Bicarbonate
Dry Creek	At Healdsburg	12/75	257	112	147	12	22	14	0.8	6.1	130	20	0	0.40	--	--	0.8	Magnesium Calcium Bicarbonate
Russian River	Near Healdsburg	7/77	302	139	173	10	29	16	1.2	6.8	160	14	0	0.80	--	--	0.0	Calcium Magnesium
		9/77													0.18	0.01		Bicarbonate
Laguna de Santa Rosa	Near Graton	7/65	237	78	150	19	30	0.7	5.4	11	112	4.3	0	0.10	--	--	6.0	Calcium Sodium
		2/62													0.11	0.15		Bicarbonate

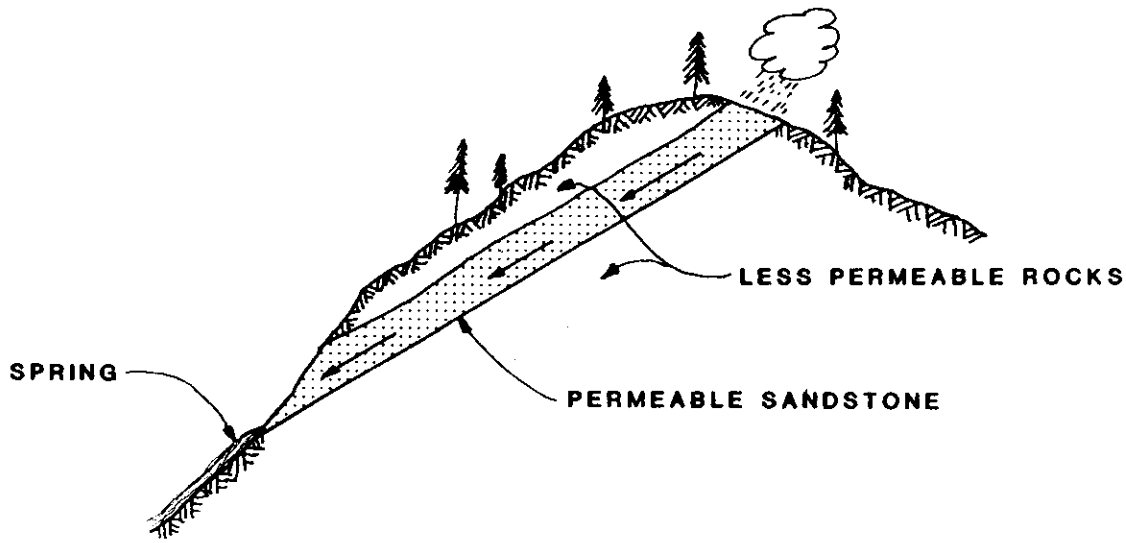
FIGURE 15

MOVEMENT OF GROUND WATER

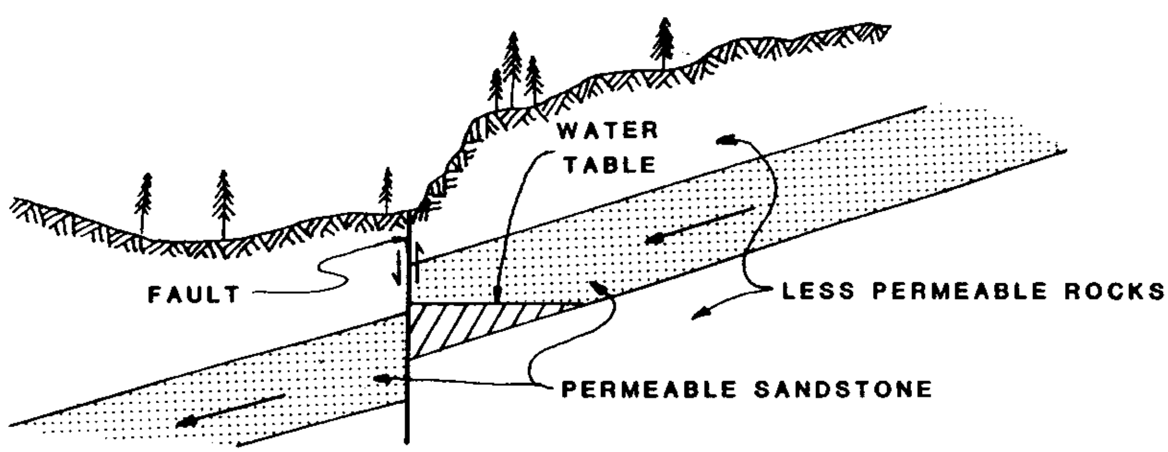
(ARROWS INDICATE DIRECTION OF GROUNDWATER MOVEMENT)



GROUND WATER MOVES DOWNDIP
UNTIL IT REACHES THE LOWEST POINT IN ELEVATION



GROUND WATER MOVES DOWNDIP UNTIL
THE PERMEABLE ROCKS ARE AGAIN AT THE SURFACE
GROUND WATER IS RELEASED AS A SPRING



TRANSMISSIVITY IS REDUCED ACROSS FAULT
GROUND WATER "STACKS UP" ON UPHILL SIDE OF FAULT

CHAPTER 6. SOURCE AND POTENTIAL MIGRATION OF SELECTED MINERAL CONSTITUENTS

Many ions and substances, when present above certain concentrations in ground water, can be harmful to humans, animals, or plants. Increased ground water pumpage near areas with water quality problems may cause the water containing these constituents to migrate.

Summary

Sodium, salinity, total dissolved solids (TDS), boron, nitrate, hardness, and iron and manganese concentrations were examined during this study. In addition, questionnaires were distributed to households using ground water to determine well owners' opinions of the taste, odor, and color of their water supply. Of these, esthetic problems with ground water, such as hardness and color, were most widespread. A single well will frequently produce water with several of the above constituents over recommended or desirable concentrations.

Because of the generally discontinuous nature of aquifers in the Santa Rosa Plain, quality problems should remain localized, barring great changes in pumping patterns. New wells pumping from depths similar to nearby wells that produce poor quality water may show similar problems, especially when pumped heavily. Because a single well usually produces water with several quality characteristics, other wells nearby should be monitored regularly to determine ground water movement. Water from wells near nitrate-contaminated wells should be analyzed regularly for nitrates. Future ground water quality sampling should include tests for iron and manganese.

Sodium

Sodium in various concentrations has been found to impair the usefulness of water for specific purposes. For example, sodium may be an undesirable constituent in the drinking water of certain people with heart problems or high blood pressure, although it is not specifically listed as such in current drinking water standards. While generally not hazardous to livestock, high concentrations of sodium ion are toxic to plant life and can adversely affect agriculture by causing soils to deflocculate or "puddle"; a hard crust forms after irrigating, adversely affecting tilth, permeability, and infiltration.

The following discussion of sodium, its effects, and its limitations refers principally to agriculture and soils, and is not intended to represent the public health aspects of this constituent.

Based on the University of California Committee of Consultants report, "Guidelines for Interpretation of Water Quality for Agriculture" (Ayers and Branson, 1975), the adjusted sodium adsorption ratio (ASAR) is used to evaluate the effect of sodium on agriculture. The ratio is computed by the following formula:

$$\mathrm{ASAR} = \left[\frac{\mathrm{Na}}{\sqrt{\frac{(\mathrm{Ca} + \mathrm{Mg})}{2}}}\right]\left[1 + (8.4 - \mathrm{pHc})\right]$$

where pHc is a calculated value based on the water analysis for total salinity (Na+Ca+Mg), on the calcium and magnesium (Ca+Mg), and on the carbonates and bicarbonates (CO_3+HCO_3), all expressed in milliequivalents per litre (see Ford, 1975, Table 20).

For ion toxicity from root absorption, problems increase as the ASAR exceeds 3; severe problems occur when the ASAR is greater than 9 (Ayers and Branson, 1975). For ion toxicity from foliar absorption, problems increase as the ASAR exceeds 3. Foliar absorption limits are important when sprinklers are used for irrigation or frost control. Previous guidelines for sodium used the SAR rather than the ASAR. The new guidelines (ASAR) recommend a lower concentration of sodium than the previous guidelines.

Of 109 wells analyzed for sodium in the Sonoma Valley, 40 were found to have ASAR values exceeding 3; 7 have ASAR values exceeding 9 (Table 4 and Figure 16A). Of the 40 wells, four had been similarly identified in Department of Water Resources Bulletin 118-4, Volume 1 (Ford, 1975), using Hem. Water from the affected wells does not represent a single quality type, although sodium is generally the dominant cation. The ASAR appears to increase with depth in those areas where the deep water is a sodium bicarbonate water.

Sodium is the most common cation in ground water in the Santa Rosa Plain. This is probably due to cation exchange between ground water and clay beds, in which the percentage of sodium in the water is increased while calcium and magnesium are absorbed by the clay particles. In the Windsor area, water containing high concentrations of sodium is present at elevations between -10 and -120 m (-40 and -390 ft). The highest concentration of sodium appears to exist between -10 and -45 m (-40 and -150 ft). Two wells east of Windsor that are also affected (8N/8W-17F1 and -20Q1) are probably intercepting the same zone. Deep wells 8N/9W-36K1 and -36P1, south of Windsor, may be affected because of the deep sodium bicarbonate water they tap.

Wells in the vicinity of Occidental Road appear to tap several different high-sodium zones. Water from a 23-m (75-ft) well (7N/8W-18M2) had an ASAR of 5.1, water from a 114-m (375-ft) well (7N/9W-13R1) had an ASAR of 11.5, and waters from two wells approximately 180 m (600 ft) deep had ASAR values ranging from 5.3 to 8.9 (7N/9W-23F1, -14K1). Insufficient construction data prevent

TABLE 4

SODIUM IN GROUND WATER
IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth		Date of Sampling	Adjusted SAR Value 1/	Degree of Hazard	
	metres	(feet)	mo/yr		Increasing	Severe
6N/7W-17D1	--	(--)	1/57	9.1		x
-17E1	198	(650)	8/60	10.3 2/		x
-18R1	76	(250)	8/77	3.3	x	
6N/8W-7A2 3/	248	(815)	9/77	3.3	x	
-13C1	153	(502)	9/79	8.0	x	
-13L1 4/	177	(580)	5/76	3.0	x	
-13R2 5/	393	(1290)	6/77	20.7		x
-14Q1 6/	461	(1512)	11/77	4.7	x	
-16G	--	(--)	5/59	14.2		x
-23H1 7/	458	(1504)	6/79	3.5	x	
7N/7W-17A1	258	(846)	6/48	4.8	x	
-18R	49 & 63	(160 & 206)	5/76	4.5 8/	x	
-20P	91+	(300+)	2/77	3.1	x	
-29D1	179	(588)	6/76	3.4	x	
-29L1	111	(365)	5/51	3.3	x	
-29L2	116	(382)	5/51	3.7	x	
-32G1	123	(403)	10/51	5.9	x	
7N/8W-3L1	46	(150)	8/78	4.0	x	
-18M1	195	(640)	12/51	7.7	x	
-18M2	23	(75)	2/52	5.1	x	
-18Q1	247	(811)	8/74	4.4	x	
-24A4	305	(1000)	7/58	3.7	x	
-24A6	278	(912)	8/50	4.9	x	
-29J1	209	(685)	2/45	4.6	x	
-29K1	20	(67)	8/78	3.1	x	
-30K1	88	(290)	6/76	5.0	x	
-31C1	238	(780	8/60	6.3	x	
7N/9W-13R1	114	(375)	2/52	11.5		x
-14K1	179	(588)	10/50	8.9	x	
-23F1	186	(610)	8/51	5.3	x	
8N/8W-17F1	108	(355)	8/77	3.3	x	
-20Q1	95	(312)	8/77	3.9	x	
8N/9W-23F1	40	(130)	7/50	3.4	x	
-23G1	68	(224)	7/50	7.1	x	
-23L1	125	(410)	7/50	5.9	x	
-26D1	139	(456)	7/50	4.4	x	
-27K1	102	(333)	7/50	5.9	x	
-36K1	404	(1325)	7/50	14.3 9/		x
-36P1	319	(1048)	9/59	20.3 10/		x

1/ All exceed recommended limit of ASAR = 3.
Sodium hazard rates severe if ASAR >9.
2/ ASAR was 4.6 in 9/63.
3/ Sonoma County Water Agency Well #4
4/ Rohnert Park Well #12
5/ Rohnert Park Well #14
6/ Rohnert Park Well #15
7/ Rohnert Park Well #16
8/ Sample mixed from two wells.
9/ ASAR was 8.3 in fall 1950.
10/ ASAR was 17.8 in 8/78.

further definition of the affected zones in this area.

Water from wells in the vicinity of Sebastopol Road appears to decrease in sodium content with depth. Water with the highest ASAR for the area is from a well (7N/8W-31C1) extracting from between 25 and -70 m (85 and -235 ft) in elevation (ASAR = 6.3). Water with the lowest ASAR hazard is from a well (6N/8W-7A2) extracting between -130 and -225 m (-420 and -735 ft) in elevation (ASAR = 3.3).

On the eastern boundary of the study area, near Santa Rosa, a number of wells ranging in depth from 50 to 305 m (160 to 1,000 ft) pump water with an ASAR of from 3.1 to 5.9 (Table 4 and Figure 16A). Sufficient construction data are not available to further define the source of this water.

In the vicinity of Rohnert Park, eight wells pump water with high concentrations of sodium -- ASAR values range from 3.0 to 20.3. Two wells, Rohnert Park No. 15 and No. 16 (6N/8W-14Q1 and -23H1), are 457 m (1,500 ft) deep. The sodium-rich water comes from a depth greater than 244 m (800 ft), as a nearby 244-m (800-ft) well (Rohnert Park No. 3, 6N/8W-23B01) does not produce water with excessive sodium. The source of sodium in water from Rohnert Park No. 14 (6N/8W-13R2) is the Sonoma Volcanics, encountered at a depth of 277 m (910 ft). There are not sufficient well construction data to evaluate the source of sodium in the remaining five wells in this area.

Wells encountering the Sonoma Volcanics beneath the valley will probably also encounter sodium-rich water. Wells drilled in areas where high sodium has been noted that are of similar construction to already affected wells may either encounter sodium-rich ground water or, if pumped heavily, may induce migration of sodium-rich ground water.

Salinity

Excessive salinity in water can kill sensitive plants and impart a salty taste to drinking water. The degree of salinity hazard is determined in different ways for agricultural and domestic water. Salinity of both agricultural and domestic water supplies is measured by electrical conductivity and chloride ion concentration.

In agriculture, salinity problems from root absorption are related to electrical conductivity (EC). Problems increase as the EC exceeds 750 microsiemens per centimetre (uS/cm). Problems are severe when the EC exceeds 3 000 uS/cm.

A related problem in agriculture is ion toxicity caused by high levels of chloride ion. Problems from foliar absorption increase as the chloride ion concentration exceeds 106 milligrams per litre (mg/L). Problems from root absorption increase as the chloride ion concentration exceeds 142 mg/L; problems are severe when the concentration exceeds 355 mg/L (Ayers and Branson, 1975).

The salinity of domestic water supplies is measured by the concentration of chloride ion and electrical conductivity. Title 22 of the California Administrative Code (California Department of Health, 1977) recommends a maximum concentration of chloride ion in drinking water of 250 mg/L; the maximum allowable concentration is 500 mg/L. Water containing more than 250 mg/L of chloride ion usually has a noticeably salty taste. The maximum recommended EC is 900 uS/cm. The upper limit is 1 600 uS/cm, although for short periods of time, water with EC values up to 2 200 uS/cm can be used.

Of the 120 wells evaluated for salinity in the Santa Rosa Plain, 28 produce water with electrical conductivities greater than 750 uS/cm; one exceeds 3 000 uS/cm. Of the 194 wells tested for chloride ion, 15 produce water with chloride ion concentrations greater than 106 mg/L and 9 exceed 142 mg/L; 3 exceed 250 mg/L and 2 exceed 500 mg/L (Table 5 and Figure 16B). Chloride ion is rare in water in the Santa Rosa Plain; of the 194 wells tested, only 22 had chloride ion as a significant anion.

Saline water can develop from contamination by volcanic emanations or marine connate water, contact with buried soil horizons containing salts, or sea water intrusion. Sea water intrusion is not a problem in the Santa Rosa Plain.

Volcanic emanations from the Sonoma Volcanics appear to be the cause of salinity problems in wells 6N/8W-13R2 and 7N/8W-13C1. Wells of similar construction that encounter the Sonoma Volcanics may show similar problems. Marine connate waters appear to be the cause of salinity problems in six of the wells drilled into the Petaluma Formation: 6N/7W-18K1 and -18R1; and 6N/8W-16G, -17H1, -17K1, and -30F2. Because of inadequate well construction data, the potential for migration of these saline waters cannot be determined.

Contact with salt-rich buried soil horizons appears to be the source of contamination of water from three shallow wells (6N/8W-8H1; 7N/8W-15G1, -29K1) and one intermediate-depth well (7N/8W-30P1). All were drilled into alluvial fan or basin deposits; the poor quality water may be perched on clay lenses within the formations. Because of the apparently limited areal extent of poor quality water, the probability of migration is low.

Sufficient data are not available to determine the source or migration potential of water from wells 6N/8W-26, 7N/8W-18Q1, and 8N/9W-36P1.

Total Dissolved Solids

The amount of total dissolved solids (TDS) in water indicates the total mineral content in the water. The recommended limit for TDS in domestic water is

TABLE 5

SALINITY OF GROUND WATER IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth		Date of Sampling	Chloride ion concentration	Electrical conductivity[1/]
	metres	(feet)	mo/yr	mg/L	µS/cm
5N/7W-8D1	---	(---)	5/47	112	910
-8D3		(138)	3/59	204	--
			4/62	--	1100
5N/8W-1Q1		(180)	2/50	133	981
-11N1		(271)	2/50	130	974
-11R1	---	(---)	10/79	--	983
-13N3	---	(---)	10/79	--	823
-14L1	---	(---)	10/79	--	768
-23D1	---	(---)	10/79	--	894
-23K1	---	(---)	10/79	--	1350
6N/7W-18R1	76.2	(250)	1/57	--	1050
6N/8W-5E1		(638)	8/51	246	--
-8H1	29.3	(96)	2/50	---	787
-13R2[2/]	393.2	(1290)	6/77	---	800
-16G	---	(---)	5/59	1240	4420
-17H1	---	(---)	8/51	274	1390
-17K2		(132)	2/50	---	1220
-26	---	(---)	2/56	625	2500
-26Q1		(170)	12/49	159	---
-30F2	87.2	(286)	8/51	---	882
7N/7W-20C1		(112)	2/50	---	854
7N/8W-13C1	237.7	(780)	9/63	104	766
-15G1	19.8	(65)	3/50	---	810
-18Q1	247.2	(811)	8/74	---	750
-21[3/]	---	(---)	10/80	190	1200
-21[4/]	---	(---)	10/80	120	1100
-29K1	15.2	(50)	8/78	173	1170
-30P.	62.5	(205)	4/67	145	---
			7/73	---	1130
7N/9W-3E1		(130)	11/49	---	1240
8N/9W-14A1		(135)	9/51	128	---
-36P1	319.4	(1048)	7/50	---	964
			9/59	110	---

Limits for chloride ion concentration:

exceeds 250 mg/L (recommended limit, human drinking water)
exceeds 106 mg/L (increasing problems, agriculture-foliar absorbtion)
between 142-355 mg/L (increasing problems, agriculture-root absorbtion)
exceeds 355 mg/L (severe problems, agriculture-root absorbtion)

1/ Electrical conductivity exceeds 750 µS (increasing problems, agriculture-root absorbtion).
2/ Rohnert Park Well No. 14. Lower 130 metres (425 feet) of well later sealed.
3/ Santa Rosa well - Meadow Lane
4/ Santa Rosa well - Brown North

500 mg/L. The maximum limit for TDS is 1 000 mg/L, although for short periods of time 1 500 mg/L is allowed (California Department of Health, 1977). Water with a TDS higher than 500 mg/L may also be expected to contain other hazardous ions, usually high sodium and salinity.

Of the 109 wells evaluated for TDS in the Santa Rosa Plain, seven produce water with TDS greater than 500 mg/L; two of these exceed 1 000 mg/L (Table 6 and Figure 16C). Each of these wells also produces water with a salinity that exceeds recommended California Department of Health standards. There appear to be areas of high TDS in the southern Santa Rosa Plain (6N/7W-18R1; 6N/8W-16G, -26), north of Santa Rosa (7N/8W-13C1), and east of Sebastopol (7N/8W-29K1, -30P1). The TDS, boron, sodium, and salinity in water from deep well 8N/9W-36P1 all exceed California Department of Health recommended standards. The source of the poor quality water is probably similar to the source of salinity, since the two parameters are related. A vertical connection between zones tapped by wells 7N/8W-29K1 and -30P1 seems likely. Migration potential is probably low, similar to that anticipated for high salinity water.

TABLE 6

TOTAL DISSOLVED SOLIDS (TDS) IN GROUND WATER IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth (metres)	Depth (feet)	Date of Sampling (month/year)	TDS (mg/L)1/
6N/7W-18R1	76	(250)	1/57	645 2/
6N/8W-16G	--	(--)	5/59	2 530
-26	--	(--)	2/56	1 370
7N/8W-13C1	238	(780)	9/63	538
-29K1	20	(67)	6/76	614
-30P1	63	(205)	7/69	638 3/
8N/9W-36P1	319	(1048)	9/59	668 4/

1/ All exceed recommended limit of Total Dissolved Solids = 500 mg/L.
2/ TDS = 392 mg/L in 7/79.
3/ TDS = 584 mg/L in 7/79.
4/ TDS = 546 mg/L in 8/78.

Nitrate

High concentrations of nitrate can cause methemoglobinemia, an oxygen deficiency in infants. For this reason, a recommended drinking water limit of 45 mg/L of nitrate (10 mg/L expressed as nitrogen) has been established by the California Administrative Code, Title 22 (California Department of Health, 1977).

Nitrates are produced by aerobic stabilization of organic nitrogen. The presence of nitrate in ground water is usually indicative of pollution from surface sources such as septic-tank leach-fields, fertilizers, or livestock and poultry farms.

Although nitrate contamination of ground water is documented in some areas in the Petaluma Valley, little water quality testing for nitrates has been done in the Santa Rosa Plain.

Of the 100 wells sampled in the Santa Rosa Plain as of spring 1979, five produce water containing in excess of 40 mg/L nitrate (Table 7 and Figure 16C).

TABLE 7

NITRATE IN GROUND WATER IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth (metres)	Depth (feet)	Date of Sampling (month/year)	Concentration of Nitrate as NO_3 (mg/L)1/
6N/7W-30R1	46	(150)	6/76	67
7N/8W-5G1	34	(110)	8/79	75
-13C1	238	(780)	9/63	80
-30P1	63	(205)	7/69	126
8N/9W-14A1	56	(185)	9/51	43

1/ All exceed recommended limit of nitrate of 45 mg/L.

The contaminated samples were taken from widely scattered locations and appear to be isolated occurrences and do not indicate regional contamination of shallow aquifers. Further sampling in the vicinity of the affected wells is needed to confirm this. Nitrate in water from well 7N/8W-30P1 appears to indicate localized contamination of a deeper aquifer. No other nearby wells for which nitrate has been analyzed produce water with this problem. Wells of similar depth near the affected wells may induce migration of nitrate-contaminated ground water if the adjacent wells begin to pump heavily. Ground water in the vicinity of the affected wells should be sampled regularly for nitrate.

In summer 1979, additional sampling for nitrate was done in the southwest corner of the study area. The results of this sampling and other sampling in the Petaluma area are described in Bulletin 118-4, Volume 3, on the Petaluma Valley.

Boron

Boron in drinking water is not generally considered a health hazard because concentrations up to 30 mg/L are not considered harmful to humans. Although a minor constituent of most water, boron is extremely important in agriculture. An amount greater than 2 mg/L is toxic to most plants, but small amounts of boron are essential to plant growth. Boron is toxic to many plants, such as citrus, grapes, apples, and walnuts, in concentrations of less than 1 mg/L. Boron concentrations below 0.5 mg/L are satisfactory for all crops (Ayers and Branson, 1975).

Of the 85 wells tested in the Santa Rosa Plain, 16 produce water with boron concentrations greater than 0.5 mg/L, and four of these 16 wells produce water with boron in excess of 2.0 mg/L (Table 8 and Figure 16D). Most of these wells have been described in either Department of Water Resources Bulletin 118-4, Volume 1, (Ford, 1975) or U. S. Geological Survey Water Supply Paper 1427 (1958). Four wells analyzed since those reports were published pump water containing boron in excess of 0.5 mg/L: Rohnert Park Municipal Wells No. 14 (6N/8W-13R2), No. 16 (-23H1), and No. 17 (-13C1), and the Sonoma County Water Agency well at Sebastopol Road (7N/9W-36K1).

High boron concentrations can be caused by:

TABLE 8

BORON IN GROUND WATER
IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth metres	(feet)	Date of Sampling (month/year)	Boron Concentration (mg/L) 1/
6N/7W-16D1	12	(38)	2/50	0.64
-17D1	--	(--)	1/57	1.2
-17E1	198	(650)	9/63	1.5
6N/8W-13C1	153	(502)	9/79	0.84
-13R2 2/	393	(1,290)	6/77	5.0
-23H1 3/	458	(1,504)	6/79	0.75
7N/8W-24A4	305	(1,000)	7/58	0.54
7N/9W-14K1	179	(588)	10/50	1.3
-36K1 4/	325	(1,065)	9/77	1.0
8N/9W-10R1	122	(400)	4/52	0.63
-13J80	122	(400)	--	1.4
-23G1	68	(224)	7/50	0.60
-23L1	125	(410)	7/50	22.4 5/
-27K1	102	(333)	7/50	1.04 6/
-36K1	404	(1,325)	9/59	4.0
-36P1	319	(1,048)	8/78	3.40 7/

1/ All exceed recommended limit of Boron = 0.5 mg/L.
2/ Rohnert Park Well 14, after sealing lower 130 metres (425 ft) of well, boron concentration dropped to less than 1 mg/L.
3/ Rohnert Park Well 16.
4/ Sonoma County Water Agency Well 1
5/ After sealing lower 56 m (183) feet of well, boron concentration dropped to 0.44 mg/L (9/50).
6/ Sample taken 1 day earlier contained 2.44 mg/L of boron.
7/ Boron = 0.60 mg/L in 7/50.

- Connate waters
- Water rising from great depths along fault zones
- Volcanic activity
- Sea water intrusion
- Buried soil horizons containing boron salts that contaminate percolating ground water.

In the Santa Rosa Plain, all water containing boron in large amounts is sodium bicarbonate water. Most of the boron appears to be related to faulting. Wells 6N/7W-16D1, -17D1, -17E1, and 7N/7W-24A4 are on or near the Rodgers Creek fault. Wells 8N/9W-36K1 and -36P1 are deep wells near the trace of a branch of Rodgers Creek fault mapped by Herd and Helley (1976). Wells 8N/9W-13J80, -23G1, -23L1, and -27K1 lie along a lineation that trends 40 degrees east of north along Windsor Creek. No further work has been done to determine the presence or absence of faulting along that lineation.

Rohnert Park No. 14 (6N/8W-13R2) intercepted flow rocks of the Sonoma Volcanics at a depth of 277 m (910 ft). The rocks contained thermal water with a boron concentration of 5 mg/L. The flow rocks containing this water have been traced to the south to Sonoma State University (Rodger Chapman, personal communication, 1981).

The source of boron in Rohnert Park Nos. 16 and 17 (6N/8W-23H1 and -13C1) is unknown; the moderate amounts of boron found in these wells may be due to poor quality connate water or a deeply buried old soil horizon. The source of boron in wells 7N/9W-14K1, -36K1, and 8N/9W-10R1 is unknown.

Heavy pumping near presently affected wells on the Rodgers Creek fault system may cause migration of boron-rich water away from the fault toward the pumping well if the new well is pumping from a similar depth. Similarly, deep wells pumping near 8N/9W-36K1 and -36P1 may cause migration. Wells deeper than approximately 275 m (900 ft) near Rohnert Park No. 14 may intercept the Sonoma Volcanics and therefore show similar quality problems. The flow intercepted by that well is irregular in areal extent; it does not extend as far into the valley as Rohnert Park No. 16 or the gas well Suyeyasu No. 2 (6N/7W-18). Rohnert Park Nos. 16 and 17 probably intercepted isolated pockets of connate water at depths less than 150 m (500 ft). Since water from nearby wells of similar depths does not have similar concentrations of boron, the boron-rich water is probably isolated and not free to migrate. Boron in the Windsor area appears to be coming from elevations of 18 to -45 m (60 to -149 ft); the elevation of the land surface ranges from approximately 24 to 30 m (80 to 100 ft).

There also appear to be several zones producing water with concentrations of boron less than 0.5 mg/L. Because boron is widespread in the Windsor area, migration induced by increased nearby pumping appears likely. Sufficient data are not available to evaluate the migration potential for wells near 7N/9W-36K1 and 8N/9W-10R1.

Hardness

Ground water containing calcium and magnesium salts is divided into two general classifications: carbonate hardness and noncarbonate hardness. Carbonate hardness becomes apparent after water has been heated, causing the soluble calcium and magnesium bicarbonates to precipitate as insoluble carbonates. The precipitates adhere to heated surfaces, such as the inside of water heaters and hot water pipes, and ultimately reduce the capacity of the fixture. Noncarbonate hardness is not affected by heat because it is principally caused by the presence of calcium sulfate; since few analyses of noncarbonate hardness in the study area are available it will not be discussed here. Both forms of hardness reduce the cleansing ability of many soaps and detergents.

The hardness of ground water is variable. Soft waters are those with a hardness of less than 60 mg/L of calcium carbonate; moderately hard waters are those with a hardness range of from 61 to 200 mg/L. Hard waters are those that have a hardness in excess of 200 mg/L.

Hardness of ground water is one of the most widespread problems of ground water in the Santa Rosa Plain. The distribution of hardness in the study area is shown in Figure 16E. In general, there is an area of soft water northwest of Santa Rosa, a large area of moderately hard water near Rohnert Park, and an area of hard water west and southwest of Santa Rosa. Areas of hard ground water correspond to areas where calcium and magnesium are the dominant cations. Hardness decreases with depth as the percentage of sodium in the ground water increases. This increase in sodium is probably due to cation exchange in clay, in which calcium and magnesium ions from ground water are affixed to clay particles and sodium ions are released.

Iron and Manganese

The presence of excessive iron and manganese in ground water is a common problem. Both of these constituents can impart a metallic taste to water or to food prepared with such water. The metallic impurities may also stain fixtures, fabrics, and utensils. The iron and manganese deposits build up in pressure tanks, water heaters, and pipes and reduce the available quantity and pressure of the water supply. The recommended limit is 0.3 mg/L for iron and 0.05 mg/L for manganese.

To obtain an accurate analysis of the amount of iron and manganese in a water sample, the sample must be acidified with nitric acid immediately after collection to stabilize the metallic constituents. If this is not done, some iron and manganese will precipitate out of solution. If plastic jugs are used for sampling, some iron and manganese will adhere to the plastic. Acidification of water samples has rarely been performed in the Santa Rosa Plain; therefore a general statement on the occurrence and movement of iron- and manganese-rich water cannot be made. Table 9 lists wells in the study area that produce water with iron or manganese in excess of recommended limits.

Sources of iron and manganese are varied. Iron is frequently present in the cementing material of sandstones and within shales. Iron is also found in the soils produced by weathering of these rocks. Iron may be added to ground water from contact with well casings, pump parts, pipes, storage tanks, and other iron objects. It can be derived from iron bacteria that grow in some well casings.

Manganese found in ground water is most frequently the result of solution of manganese from soils and sediments aided by anaerobic bacteria under reducing conditions.

In some parts of California, water rich in iron and manganese occurs near the bottom of various individual aquifers. Because iron and manganese ions are relatively heavy, they tend to settle in an aquifer until they are concentrated just above a clay bed. Water drawn from a well perforated near the bottom of an aquifer would therefore tend to have a greater concentration of iron and manganese. In the Santa Rosa Plain, however, data are insufficient to evaluate this phenomenon.

TABLE 9

IRON AND MANGANESE IN GROUND WATER IN EXCESS OF RECOMMENDED STANDARDS

Well Number	Depth metres	Depth (feet)	Date of Sampling (mo/yr)	Iron Concentration Total[1] (mg/L)	Iron Concentration Dissolved (mg/L)	Manganese Conc. (mg/L)
6N/7W-5A1	37	(120)	4/60	5.0		0.48
-17E1	198	(650)	9/61	0.79		(0)[2]
-31H1	91	(298)	5/47		(0.03)[2]	0.07
6N/8W-2E1	52	(172)	8/74	(0.08)[2]		0.77
-5	195	(638)	8/61	47		--
-7A2[3]	248	(815)	11/77	(0.2)		0.4
-13C1	153	(502)	9/79	0.30		0.16
-13L1[4]	177	(580)	5/76	(0.06)		0.07
-13R2[5]	393	(1290)	2/78	0.86		0.08
-14Q1[6]	461	(1512)	11/77	0.98		0.60
-15J3	51	(166)	5/47		4.7	(0.03)
-16R1	173	(568)	9/61	0.44		0.50
-23B1[7]	245	(804)	2/78	(<0.10)		0.34
-23H1[8]	458	(1504)	6/79	(0.15)		0.60
-24E1[9]	151	(496)	5/74	1.00		(<0.05)
-24G1[10]	138	(451)	4/74	0.34		(<0.05)
-25F1[11]	152	(500)	9/76	(0.24)		<0.06
-25Q1	--	(--)	5/47		(0)	0.09
-26A1[12]	141	(462)	2/78	0.49		(<0.05)
-35A2	201	(660)	8/77	1.1		0.1
-35G	--	(--)	1/76	0.72		(0.04)
-36A1	111	(363)	5/47		1.56	(0)
-36A2[13]	155	(510)	1/73	0.70		(<0.05)
6N/9W-1M80	174	(572)	5/74	0.38		(<0.05)
-2B80	161	(528)	2/77	(<0.02)		<0.06
-2C1	183	(600)	2/77	(0.09)		<0.06
-2H1	23	(75)	2/77	(<0.02)		<0.06
7N/7W-15C1	121	(397)	9/61	0.74		0.53
-17A1	258	(846)	6/48		(0.06)	0.12
7N/7W-18R1[14]	49	(160)	1/48		0.33	0.10
-18R	49 & 63	(160 & 206)	5/76	(0.22)		0.06[15]
-20P	91+	(300+)	2/77	0.37		<0.06
-29D1	179	(588)	9/61	0.52		0.08
7N/8W-3L1	46	(150)	5/46	2.7		--
-3M	84	(275)	7/77	0.3		0.48
-9Q1	43	(140)	2/50		0.32	0.20
-9R1	64	(210)	2/50		0.86	0.32
-13P1	18	(60)	9/61	1.6		0.30
-14D1	91	(300)	2/50		0.98	0.54
-15Q	249	(817)	5/73	0.95		1.17
-19J1	57	(186)	2/50		0.90	0.44
-20C1	191	(625)	2/50		0.93	0.77
-20K1	191	(626)	2/50		(0.06)	0.22
-21P	97	(319)	3/77	0.40		0.30
-23M	302	(990)	3/77	0.32		0.34
-24A2	284	(930)	1/48		(0.23)	0.09
-24A3	91	(300)	1/48		(0.29)	0.13
-24A4	305	(1000)	1/48		0.33	0.09
-24A6	278	(912)	9/61	1.1		0.3
-29J1	209	(685)	2/50		0.39	0.28
-31L1	238	(780)	9/61	(0)		0.06
-33M1	138	(452)	9/61	0.51		0.48
7N/9W-9F1	69	(226)	9/61	0.63		--
-29R1	156	(512)	9/61	12		(0)
-36K1[16]	325	(1065)	9/77	1.1		0.09
-36M1	27	(88)	9/61	0.74		(0)
8N/9W-12P1	57	(187)	6/75	7.6		0.48

1/ Value for iron given as "Total" or no distinction made as to type of analysis.
2/ Parenthese indicate concentration is below recommended limits of 0.3 mg/L iron or 0.05 mg/L manganese.
3/ Sonoma County Water Agency Well #4
4/ Rohnert Park Well #12
5/ Rohnert Park Well #14
6/ Rohnert Park Well #15
7/ Rohnert Park Well #3
8/ Rohnert Park Well #16
9/ Rohnert Park Well #11
10/ Rohnert Park Well #10
11/ Rohnert Park Well #13
12/ Rohnert Park Well #2
13/ Rohnert Park Well #8
14/ Well #18R1 is same as 49m. Well listed under 18R.
15/ Water sample mixed from two wells.
16/ Sonoma County Water Agency Well #1

EXPLANATION

● ASAR = 3.0 - 9.0 INCREASING PROBLEMS FOR AGRICULTURAL USE

○ ASAR > 9.0 SEVERE PROBLEMS FOR AGRICULTURAL USE

ASAR = ADJUSTED SODIUM ABSORPTION RATIO

FOR DATES OF ANALYSES, SEE TABLE 4

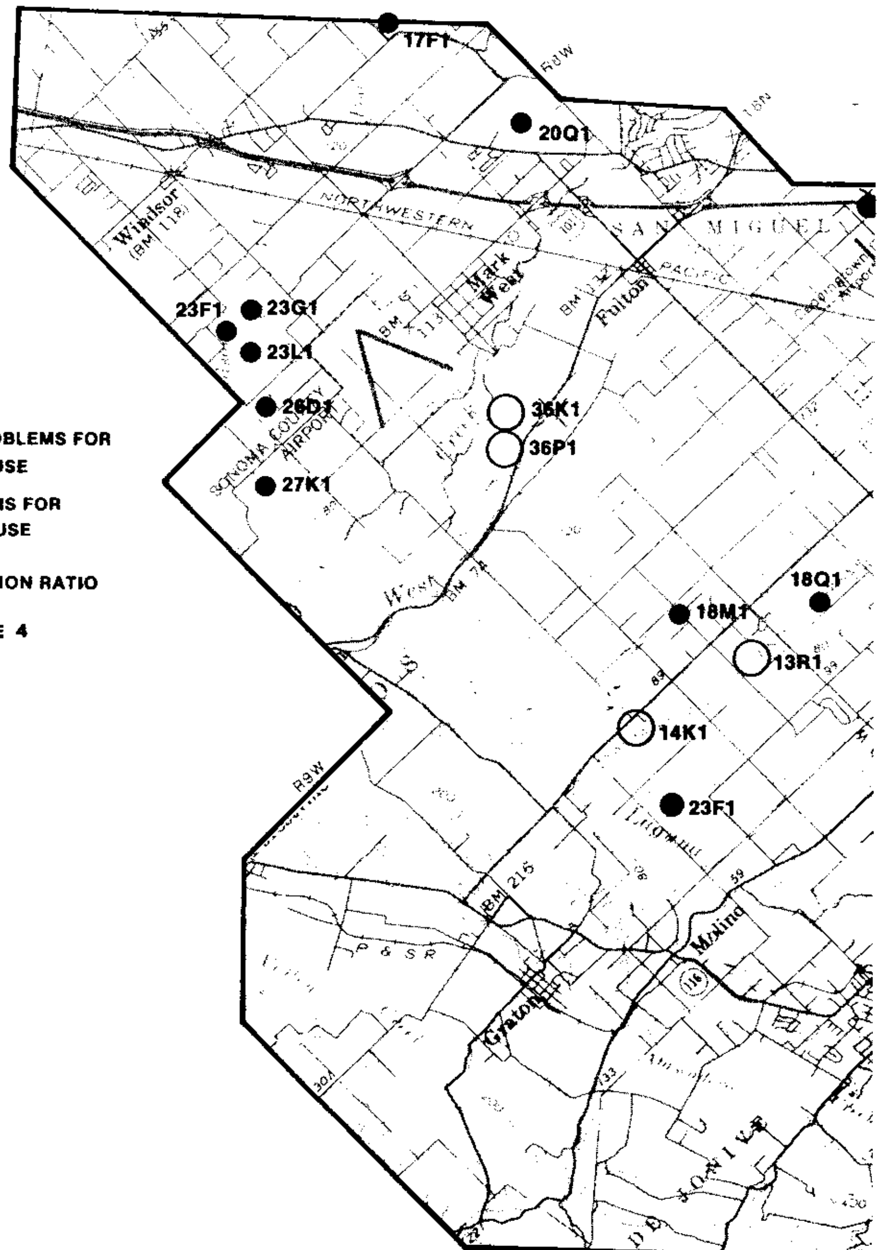
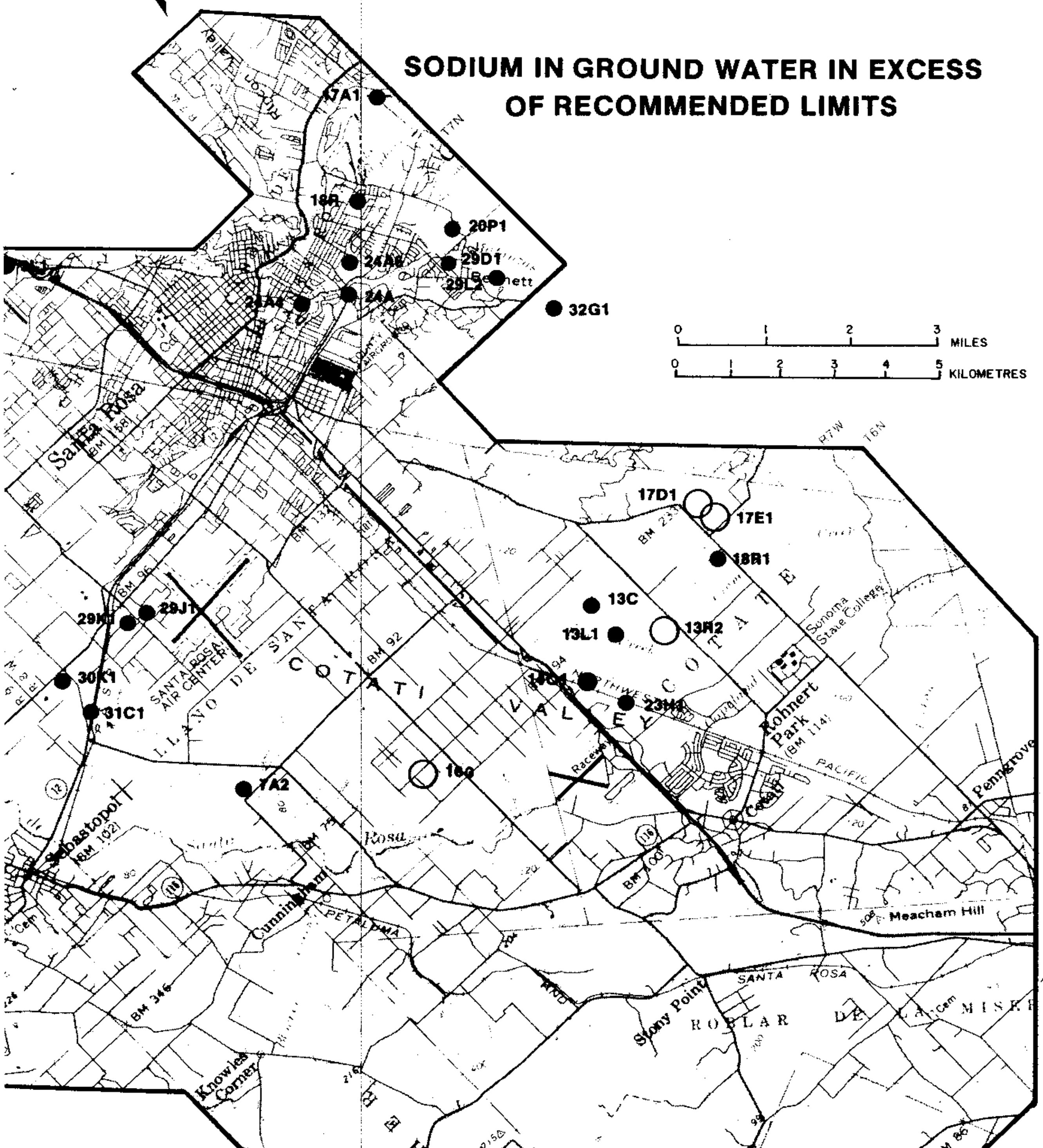


FIGURE 16 A

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN



EXPLANATION

E.C. = 150 - 3000 uS/cm — INCREASING PROBLEMS FOR AGRICULTURAL USE

E.C. 3000 uS/cm — SEVERE PROBLEMS FOR AGRICULTURAL USE

E.C. = ELECTRICAL CONDUCTIVITY

CHLORIDE CONCENTRATION:

- 106 - 141 mg/l
- 142 - 249 mg/l
- 250 -499 mg/l
- > 500 mg/l

AGRICULTURAL USE:

106 mg/l INCREASING PROBLEMS - FOLIAR ABSORPTION

142 mg/l INCREASING PROBLEMS - ROOT ABSORPTION

DRINKING WATER:

250 mg/l RECOMMENDED LIMIT

500 mg/l MAXIMUM LIMIT

FOR DATES OF ANALYSES, SEE TABLE 5

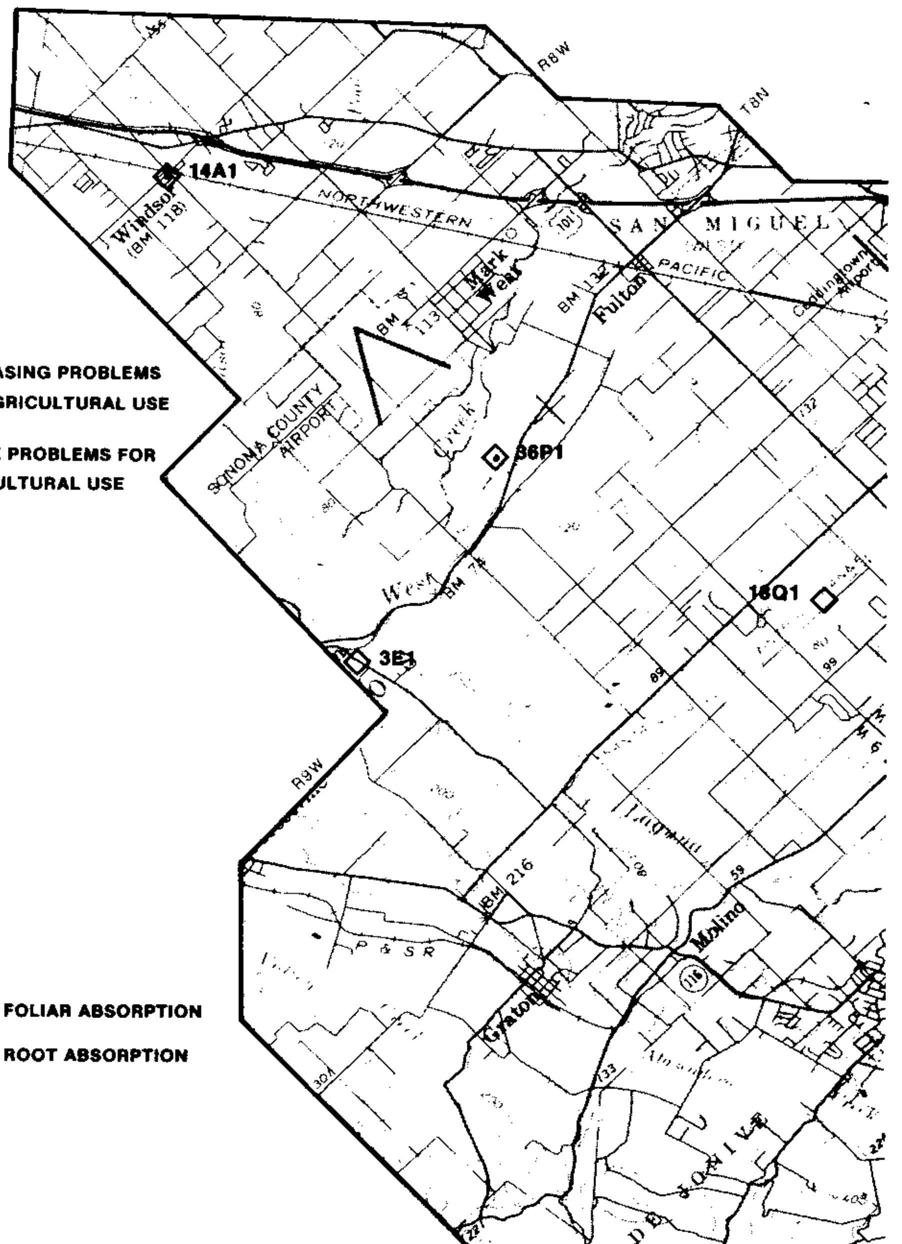
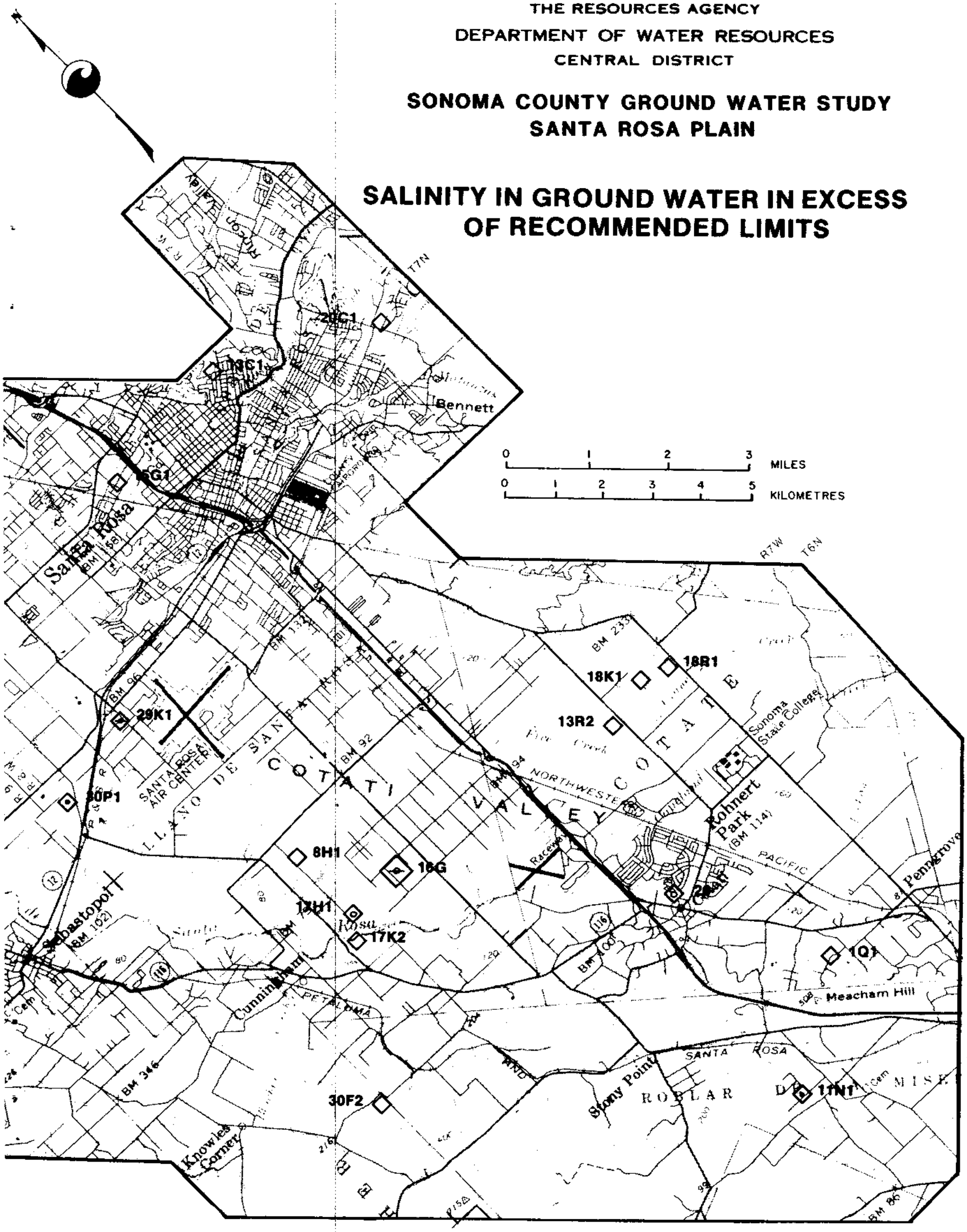


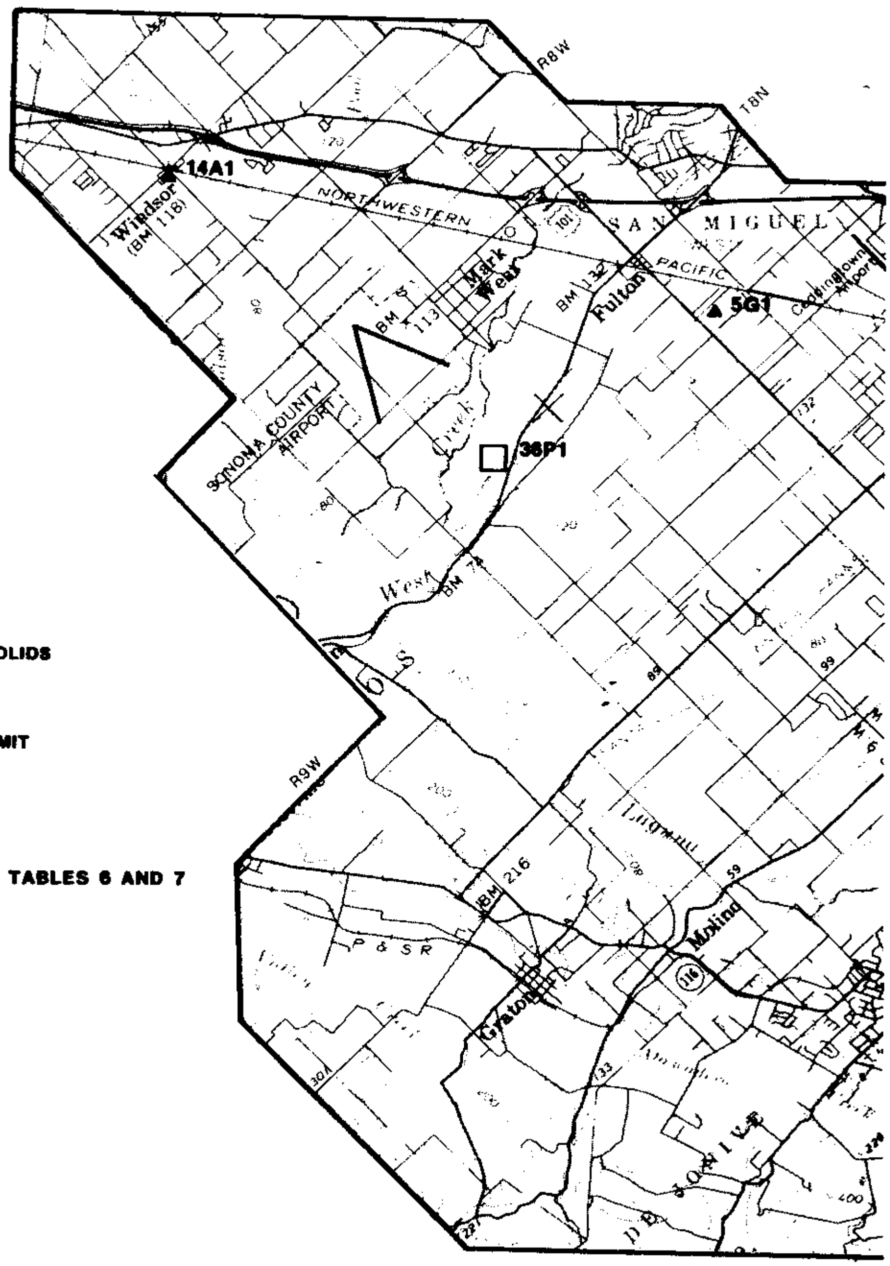
FIGURE 16 B

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

SALINITY IN GROUND WATER IN EXCESS OF RECOMMENDED LIMITS





EXPLANATION

□ TDS = 500 - 1000 mg/l

□ TDS > 1000 mg/l

TDS = TOTAL DISSOLVED SOLIDS

DRINKING WATER:

500 mg/l RECOMMENDED LIMIT

1000 mg/l MAXIMUM LIMIT

▲ NITRATE > 45 mg/l

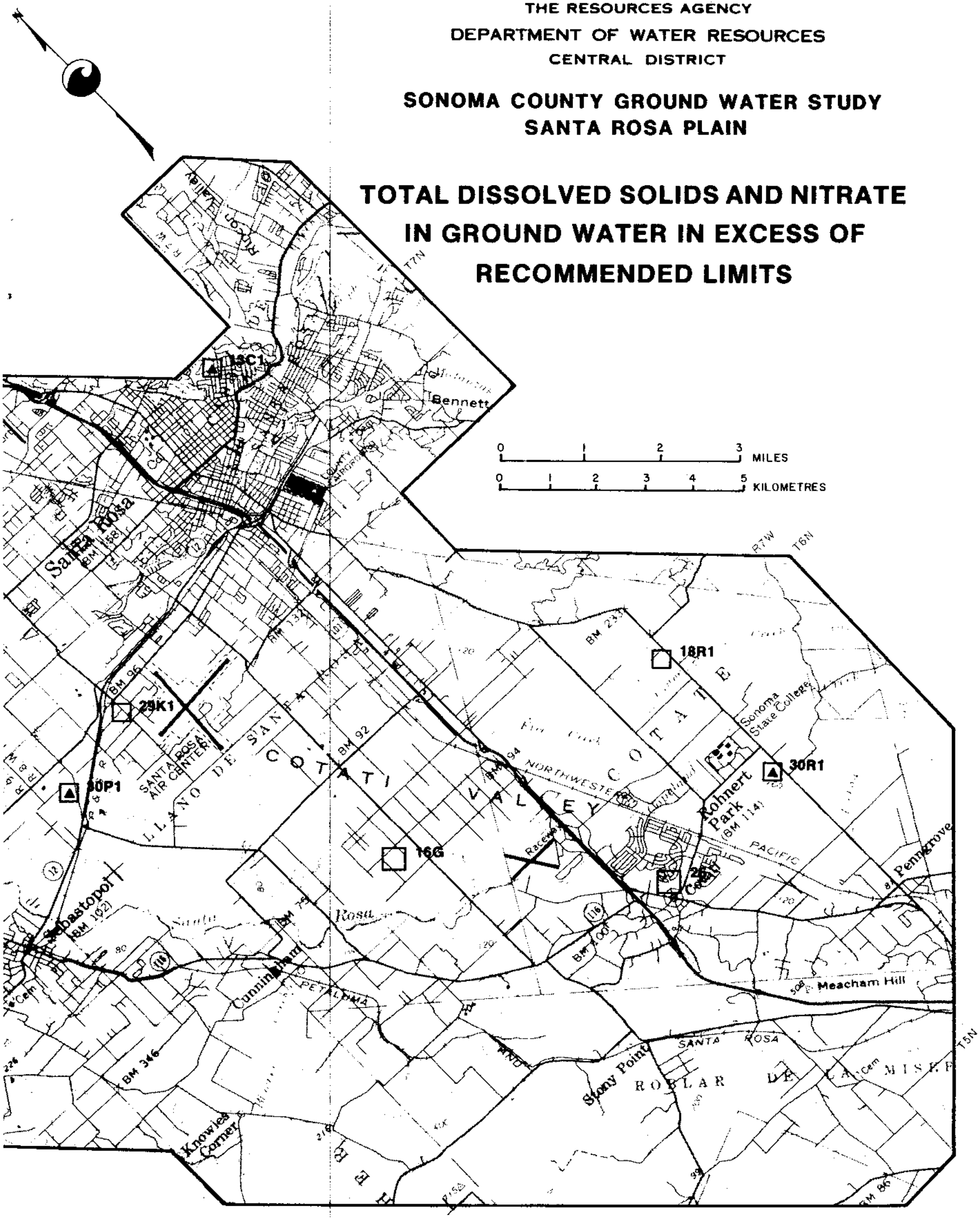
FOR DATES OF ANALYSES, SEE TABLES 6 AND 7

FIGURE 16 C

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

TOTAL DISSOLVED SOLIDS AND NITRATE IN GROUND WATER IN EXCESS OF RECOMMENDED LIMITS



EXPLANATION

BORON

●	0.5 - 2.0 mg/l	INCREASING PROBLEMS FOR AGRICULTURAL USE
⬡	Over 2.0 mg/l	SEVERE PROBLEMS FOR AGRICULTURAL USE

FOR DATES OF ANALYSES, SEE TABLE 8

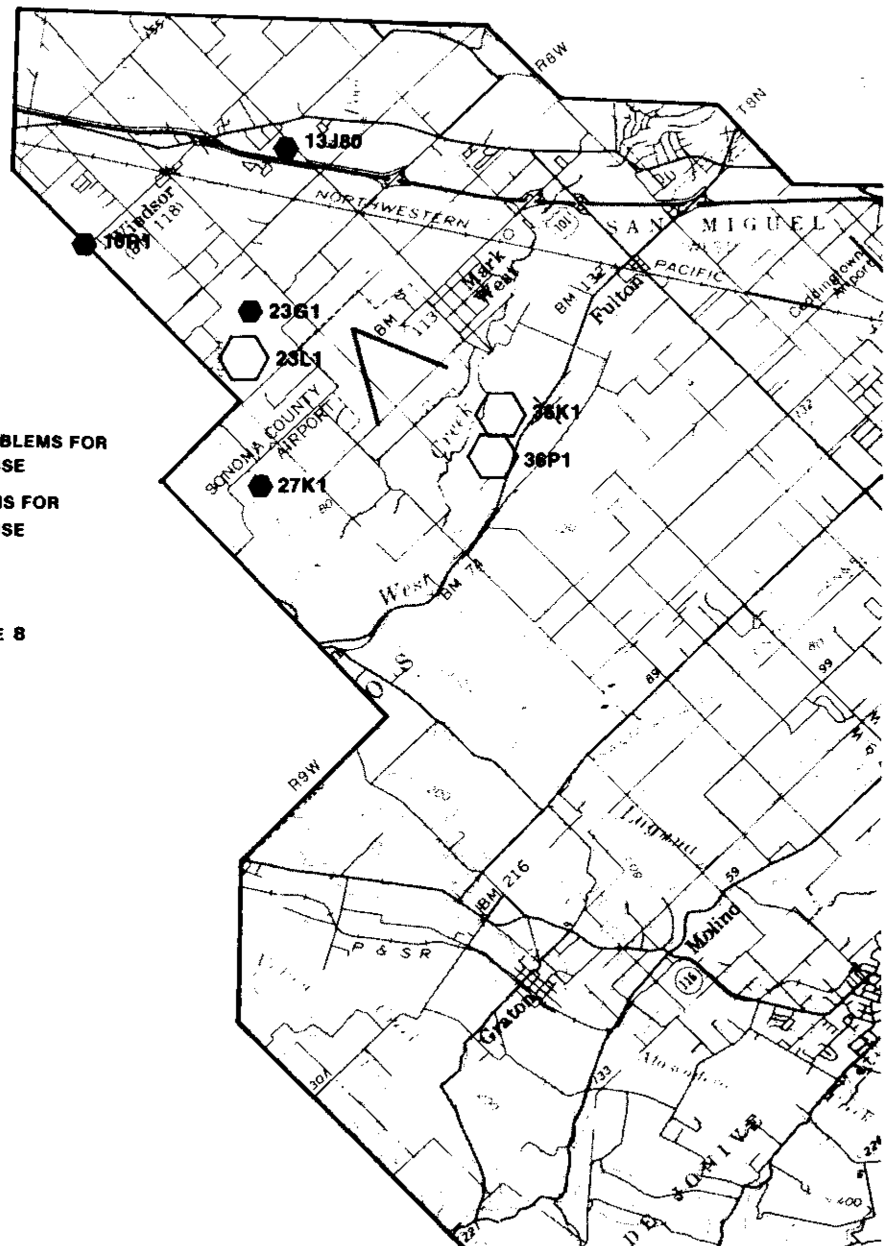
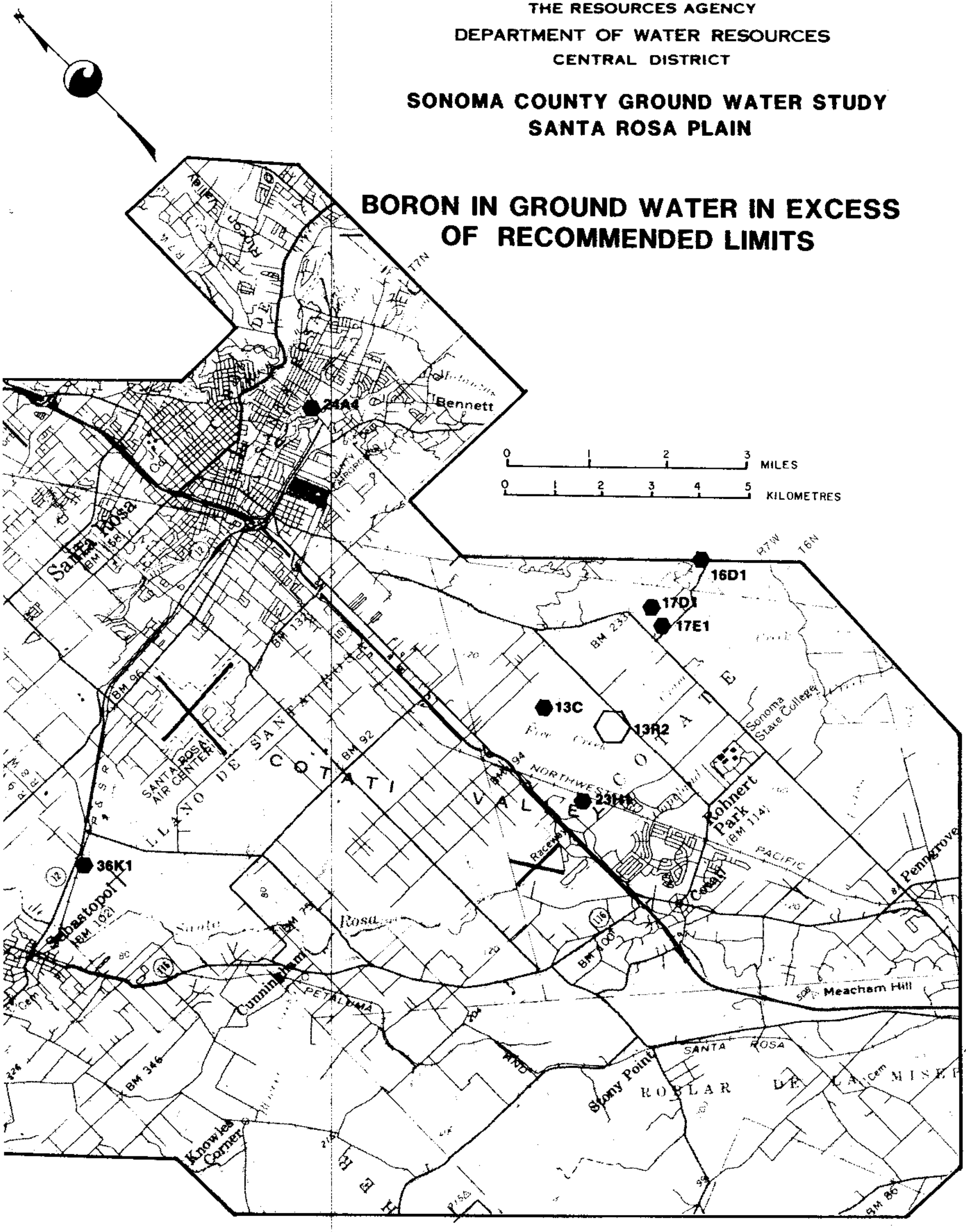


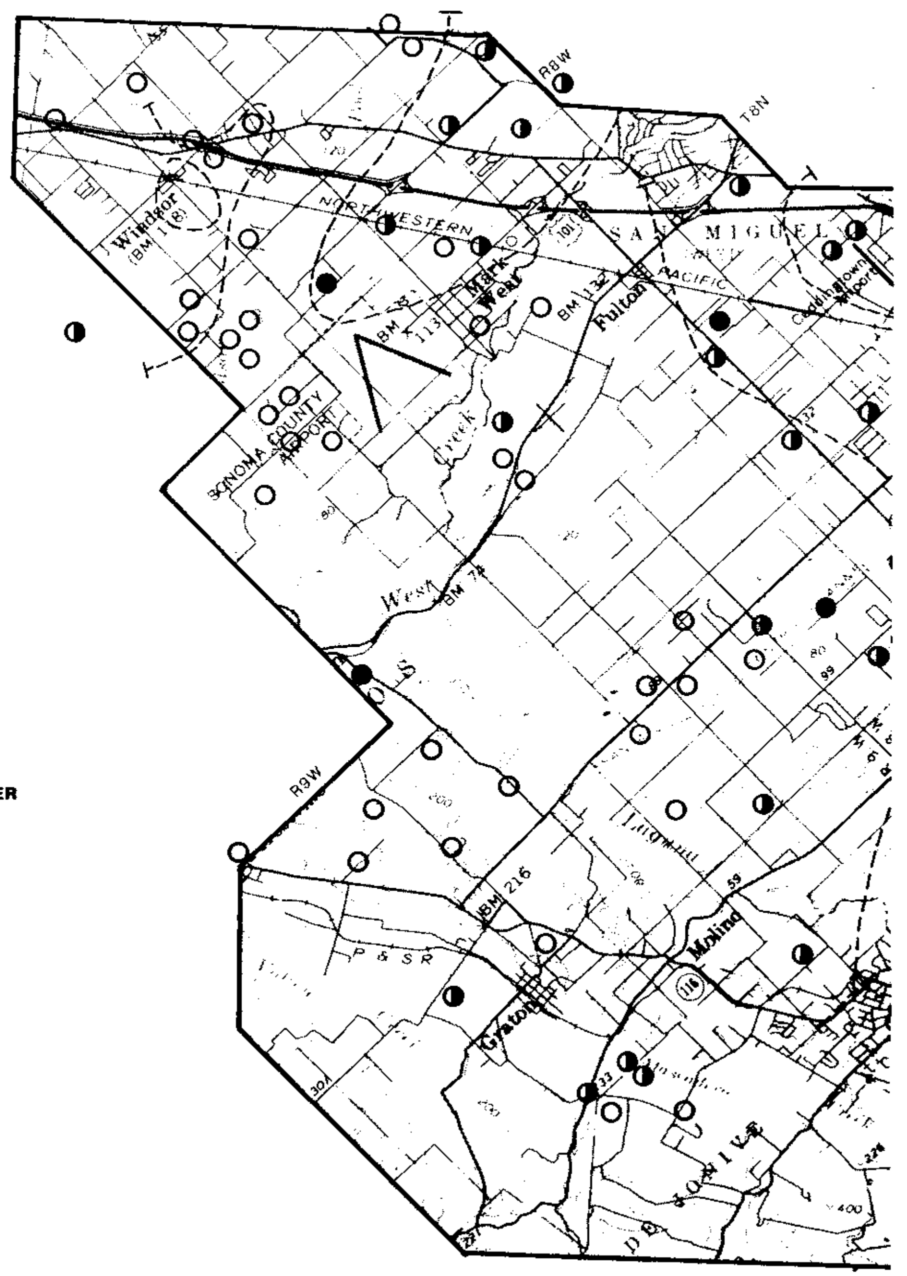
FIGURE 16 D

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

BORON IN GROUND WATER IN EXCESS OF RECOMMENDED LIMITS





EXPLANATION

HARDNESS CONCENTRATION (mg/l)

- ○ SOFT 0-100
- ◑ MODERATELY HARD 101-200
- ● HARD 201-400+

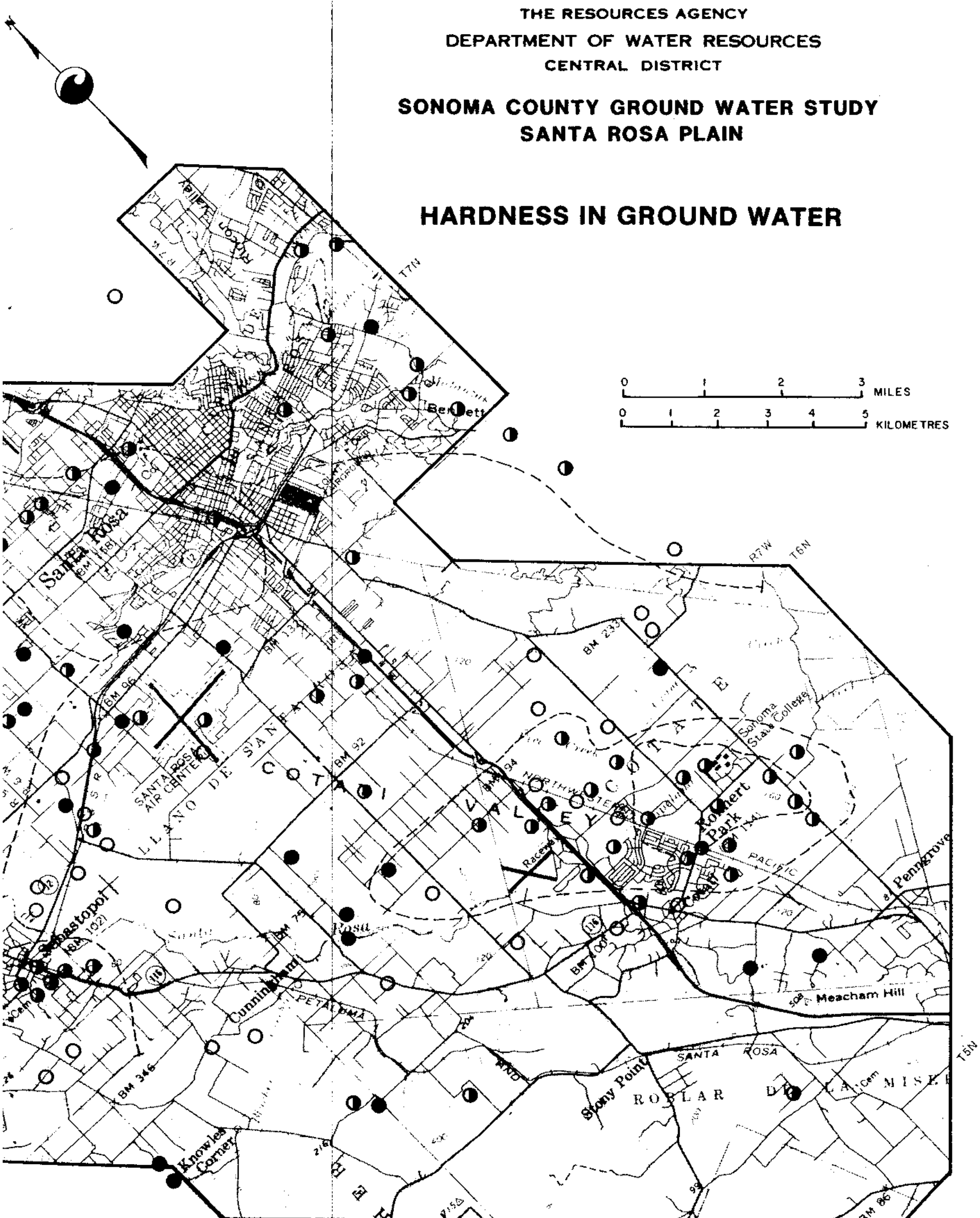
DASHED LINES ENCLOSE DIFFERENT WATER QUALITY TYPES (SEE FIGURE 13)

FIGURE 16 E

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN

HARDNESS IN GROUND WATER



Well Owner Questionnaire Results

To determine well owners' opinions of their ground water quality, the Sonoma County Water Agency mailed questionnaires in 1977 to all rural property owners in Sonoma County who do not receive water from municipal water systems. The questionnaires requested information on ground water taste, odor, and color. The responses were grouped according to assessor's parcel books (Figure 17).

Within each parcel book area, responses were separated according to well depth:

° Shallow wells, 0-46 m (0-150 ft) deep.

° Intermediate wells, 46-107 m (151-350 ft) deep.

° Deep wells, greater than 107 m (350 ft) deep.

Within each depth range, the number of wells with each of the following problems was tabulated:

° Taste
° Odor
° Color
° Other (problem)
° None (no problem)

Since a single well could have more than one problem, two other tabulations were added: (1) taste, odor, or color; and (2) taste, odor, color, or other. The responses to the questionnaires are tabulated in Table 10.

Color was the most common complaint about water from shallow and intermediate depth wells, although there were many complaints about taste and some about odor. Fewer complaints were reported about deep wells, and no complaint was distinctly more common.

Some common causes of colored water are excessive iron and manganese and the pumping of sand. Some causes of unpleasant taste are excessive hardness, salinity, sodium, iron and manganese, and sulfides. Unpleasant odor can be caused by excessive iron and manganese or hydrogen sulfide.

FIGURE 17

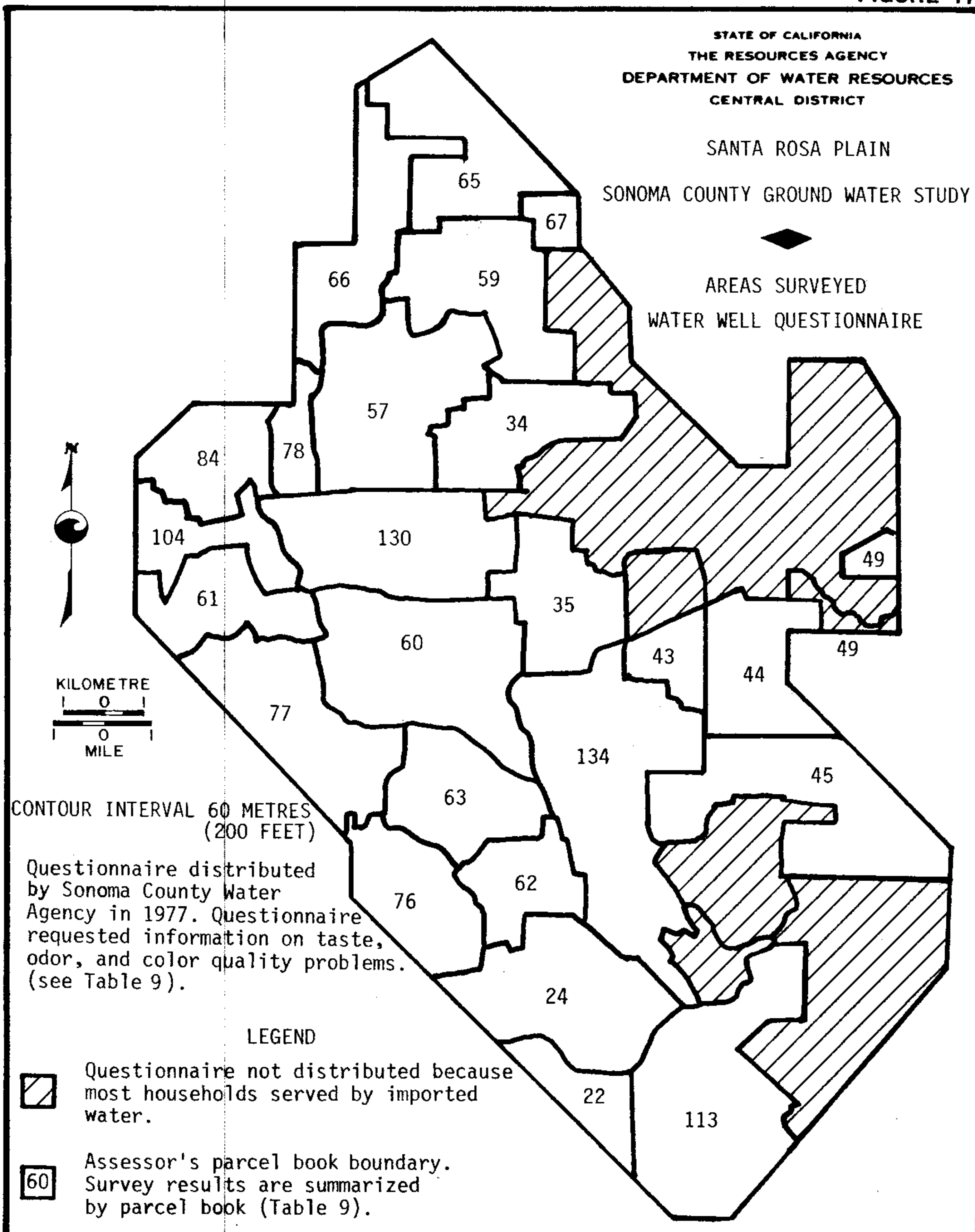

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
SANTA ROSA PLAIN
SONOMA COUNTY GROUND WATER STUDY
AREAS SURVEYED
WATER WELL QUESTIONNAIRE
65
67
66
59
57
34
84
78
104
130
61
35
49
60
43
44
49
77
134
45
63
62
76
24
22
113
KILOMETRE
0
0
MILE
CONTOUR INTERVAL 60 METRES
(200 FEET)
Questionnaire distributed by Sonoma County Water Agency in 1977. Questionnaire requested information on taste, odor, and color quality problems. (see Table 9).
LEGEND
Questionnaire not distributed because most households served by imported water.
60
Assessor's parcel book boundary. Survey results are summarized by parcel book (Table 9).

TABLE 10

WATER WELL QUESTIONNAIRE RESPONSES

ASSESSORS PARCEL BOOK NO. 27 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	12	1	0	0	13
ODOR	0	1	0	0	1
COLOR	8	0	0	0	8
OTHER	1	1	0	0	2
NONE	29	10	0	9	48
TASTE, ODOR OR COLOR	14	2	0	0	16
TASTE, ODOR, COLOR OR OTHER	15	3	0	0	18
NUMBER OF WELLS IN SURVEY	44	13	0	9	66
% WELLS WITH T,O,C QUALITY PROBLEM	31.8%	15.4%	N/A	.0%	24.2%
% WELLS WITH T,O,C,X QUALITY PROBLEM	34.1%	23.1%	N/A	.0%	27.3%

ASSESSORS PARCEL BOOK NO. 24 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	3	3	1	4	11
ODOR	2	3	0	6	11
COLOR	1	4	0	6	11
OTHER	0	4	0	1	5
NONE	12	7	0	4	23
TASTE, ODOR OR COLOR	3	6	1	6	16
TASTE, ODOR, COLOR OR OTHER	3	10	1	7	21
NUMBER OF WELLS IN SURVEY	15	17	1	11	44
% WELLS WITH T,O,C QUALITY PROBLEM	20.0%	35.3%	100.0%	54.5%	36.4%
% WELLS WITH T,O,C,X QUALITY PROBLEM	20.0%	58.8%	100.0%	63.6%	47.7%

ASSESSORS PARCEL BOOK NO. 34 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	16	2	0	5	23
ODOR	17	2	0	8	27
COLOR	18	1	0	5	24
OTHER	17	1	1	6	25
NONE	100	6	2	40	148
TASTE, ODOR OR COLOR	25	3	0	11	39
TASTE, ODOR, COLOR OR OTHER	36	4	1	14	55
NUMBER OF WELLS IN SURVEY	136	10	3	54	203
% WELLS WITH T,O,C QUALITY PROBLEM	18.4%	30.0%	.0%	20.4%	19.2%
% WELLS WITH T,O,C,X QUALITY PROBLEM	26.5%	40.0%	33.3%	25.9%	27.1%

ASSESSORS PARCEL BOOK NO. 35 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	1	0	0	6	7
ODOR	2	0	0	5	7
COLOR	1	0	0	6	7
OTHER	3	1	0	1	5
NONE	88	5	1	51	145
TASTE, ODOR OR COLOR	4	0	0	9	13
TASTE, ODOR, COLOR OR OTHER	7	1	0	9	17
NUMBER OF WELLS IN SURVEY	95	6	1	60	162
% WELLS WITH T,O,C QUALITY PROBLEM	4.2%	.0%	.0%	15.0%	8.0%
% WELLS WITH T,O,C,X QUALITY PROBLEM	7.4%	16.7%	.0%	15.0%	10.5%

ASSESSORS PARCEL BOOK NO. 43 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	0	0	0	0	0
ODOR	0	0	0	0	0
COLOR	1	0	0	0	1
OTHER	1	0	0	1	2
NONE	18	2	0	16	36
TASTE, ODOR OR COLOR	1	0	0	0	1
TASTE, ODOR, COLOR OR OTHER	2	0	0	1	3
NUMBER OF WELLS IN SURVEY	20	2	0	17	39
% WELLS WITH T,O,C QUALITY PROBLEM	5.0%	.0%	N/A	.0%	2.6%
% WELLS WITH T,O,C,X QUALITY PROBLEM	10.0%	.0%	N/A	5.9%	7.7%

ASSESSORS PARCEL BOOK NO. 44 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM: SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	1	1	0	0	2
ODOR	1	0	0	0	1
COLOR	7	3	0	1	11
OTHER	1	2	0	0	3
NONE	14	6	0	6	26
TASTE, ODOR OR COLOR	7	4	0	1	12
TASTE, ODOR, COLOR OR OTHER	8	5	0	1	14
NUMBER OF WELLS IN SURVEY	22	11	0	7	40
% WELLS WITH T,O,C QUALITY PROBLEM	31.8%	36.4%	N/A	14.3%	30.0%
% WELLS WITH T,O,C,X QUALITY PROBLEM	36.4%	45.5%	N/A	14.3%	35.0%

ASSESSORS PARCEL BOOK NO. 45 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	0	0	0	0	0
ODOR	0	0	0	0	0
COLOR	0	0	0	0	0
OTHER	0	0	0	0	0
NONE	1	0	0	0	1
TASTE, ODOR OR COLOR	0	0	0	0	0
TASTE, ODOR, COLOR OR OTHER	0	0	0	0	0
NUMBER OF WELLS IN SURVEY	1	0	0	0	1
% WELLS WITH T.O.C QUALITY PROBLEM	.0%	N/A	N/A	N/A	.0%
% WELLS WITH T.O.C.X QUALITY PROBLEM	.0%	N/A	N/A	N/A	.0%

ASSESSORS PARCEL BOOK NO. 49 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	17	15	3	7	42
ODOR	15	16	3	6	40
COLOR	21	17	4	6	48
OTHER	12	7	4	3	26
NONE	16	12	9	10	47
TASTE, ODOR OR COLOR	25	23	6	9	63
TASTE, ODOR, COLOR OR OTHER	32	27	9	11	79
NUMBER OF WELLS IN SURVEY	48	39	18	21	126
% WELLS WITH T.O.C QUALITY PROBLEM	52.1%	59.0%	33.3%	42.9%	50.0%
% WELLS WITH T.O.C.X QUALITY PROBLEM	66.7%	69.2%	50.0%	52.4%	62.7%

ASSESSORS PARCEL BOOK NO. 57 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	15	1	0	7	23
ODOR	16	2	0	11	29
COLOR	14	1	0	7	22
OTHER	15	1	0	4	20
NONE	25	11	0	13	49
TASTE, ODOR OR COLOR	24	4	0	16	44
TASTE, ODOR, COLOR OR OTHER	32	4	0	16	52
NUMBER OF WELLS IN SURVEY	57	15	0	29	101
% WELLS WITH T.O.C QUALITY PROBLEM	42.1%	26.7%	N/A	55.2%	43.6%
% WELLS WITH T.O.C.X QUALITY PROBLEM	56.1%	26.7%	N/A	55.2%	51.5%

ASSESSORS PARCEL BOOK NO. 59 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	17	2	0	9	28
ODOR	11	2	0	7	20
COLOR	16	2	0	13	31
OTHER	10	3	0	3	16
NONE	44	13	1	16	74
TASTE, ODOR OR COLOR	23	3	0	13	39
TASTE, ODOR, COLOR OR OTHER	31	5	0	15	51
NUMBER OF WELLS IN SURVEY	75	18	1	31	125
% WELLS WITH T.O.C QUALITY PROBLEM	30.7%	16.7%	.0%	41.9%	31.2%
% WELLS WITH T.O.C.X QUALITY PROBLEM	41.3%	27.8%	.0%	48.4%	40.8%

ASSESSORS PARCEL BOOK NO. 60 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	10	10	2	11	33
ODOR	7	7	2	7	23
COLOR	12	17	1	12	42
OTHER	15	9	3	10	37
NONE	73	38	4	35	150
TASTE, ODOR OR COLOR	18	20	2	15	55
TASTE, ODOR, COLOR OR OTHER	32	27	5	22	86
NUMBER OF WELLS IN SURVEY	105	65	9	57	236
% WELLS WITH T.O.C QUALITY PROBLEM	17.1%	30.6%	22.2%	26.3%	23.3%
% WELLS WITH T.O.C.X QUALITY PROBLEM	30.5%	41.5%	55.6%	38.6%	36.4%

ASSESSORS PARCEL BOOK NO. 61 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	20	35	3	14	72
ODOR	12	28	3	13	56
COLOR	23	54	4	23	104
OTHER	17	24	5	1	46
NONE	22	19	4	6	51
TASTE, ODOR OR COLOR	26	59	5	23	113
TASTE, ODOR, COLOR OR OTHER	29	66	10	23	130
NUMBER OF WELLS IN SURVEY	51	87	14	29	181
% WELLS WITH T.O.C QUALITY PROBLEM	51.0%	67.8%	35.7%	79.3%	62.4%
% WELLS WITH T.O.C.X QUALITY PROBLEM	56.9%	78.2%	71.4%	79.3%	71.8%

ASSESSORS PARCEL BOOK NO. 62 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM

QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	31	19	3	10	63
ODOR	21	22	1	7	51
COLOR	42	36	3	11	92
OTHER	17	19	1	4	41
NONE	50	29	2	12	93
TASTE, ODOR OR COLOR	52	40	4	14	110
TASTE, ODOR, COLOR OR OTHER	59	47	5	16	127
NUMBER OF WELLS IN SURVEY	109	76	7	28	220
% WELLS WITH T,O,C QUALITY PROBLEM	47.7%	52.6%	57.1%	50.0%	50.0%
% WELLS WITH T,O,C,X QUALITY PROBLEM	54.1%	61.8%	71.4%	57.1%	57.7%

ASSESSORS PARCEL BOOK NO. 63 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM

QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	24	11	10	13	58
ODOR	10	10	8	11	39
COLOR	39	18	14	21	92
OTHER	38	18	5	8	69
NONE	88	13	4	22	127
TASTE, ODOR OR COLOR	51	23	16	23	113
TASTE, ODOR, COLOR OR OTHER	77	34	18	28	157
NUMBER OF WELLS IN SURVEY	165	47	22	50	284
% WELLS WITH T,O,C QUALITY PROBLEM	30.9%	48.9%	72.7%	46.0%	39.8%
% WELLS WITH T,O,C,X QUALITY PROBLEM	46.7%	72.3%	81.8%	56.0%	55.3%

ASSESSORS PARCEL BOOK NO. 65 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM

QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	21	12	3	4	40
ODOR	15	9	2	3	29
COLOR	20	11	2	6	39
OTHER	14	2	1	1	18
NONE	34	14	3	20	71
TASTE, ODOR OR COLOR	33	18	5	7	63
TASTE, ODOR, COLOR OR OTHER	39	19	5	8	71
NUMBER OF WELLS IN SURVEY	73	33	8	28	142
% WELLS WITH T,O,C QUALITY PROBLEM	45.2%	54.5%	62.5%	25.0%	44.4%
% WELLS WITH T,O,C,X QUALITY PROBLEM	53.4%	57.6%	62.5%	28.6%	50.0%

ASSESSORS PARCEL BOOK NO. 66 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM

QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	21	2	2	9	34
ODOR	15	2	0	7	24
COLOR	24	2	0	4	30
OTHER	15	4	0	8	27
NONE	82	7	1	20	110
TASTE, ODOR OR COLOR	32	3	2	10	47
TASTE, ODOR, COLOR OR OTHER	42	6	2	15	65
NUMBER OF WELLS IN SURVEY	124	13	3	35	175
% WELLS WITH T,O,C QUALITY PROBLEM	25.8%	23.1%	66.7%	28.6%	26.9%
% WELLS WITH T,O,C,X QUALITY PROBLEM	33.9%	46.2%	66.7%	42.9%	37.1%

ASSESSORS PARCEL BOOK NO. 67 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM

QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	1	3	0	2	6
ODOR	3	5	0	1	9
COLOR	1	5	1	2	9
OTHER	3	6	0	2	11
NONE	11	13	0	3	27
TASTE, ODOR OR COLOR	4	11	1	2	18
TASTE, ODOR, COLOR OR OTHER	7	14	1	4	26
NUMBER OF WELLS IN SURVEY	18	27	1	7	53
% WELLS WITH T,O,C QUALITY PROBLEM	22.2%	40.7%	100.0%	28.6%	34.0%
% WELLS WITH T,O,C,X QUALITY PROBLEM	38.9%	51.9%	100.0%	57.1%	49.1%

ASSESSORS PARCEL BOOK NO. 76 — NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM

QUALITY PROBLEM	SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	20	52	8	11	91
ODOR	16	36	11	8	71
COLOR	22	74	9	14	119
OTHER	14	32	4	7	57
NONE	34	25	6	20	85
TASTE, ODOR OR COLOR	28	83	11	15	137
TASTE, ODOR, COLOR OR OTHER	35	96	12	20	163
NUMBER OF WELLS IN SURVEY	69	121	18	40	248
% WELLS WITH T,O,C QUALITY PROBLEM	40.6%	68.6%	61.1%	37.5%	55.2%
% WELLS WITH T,O,C,X QUALITY PROBLEM	50.7%	79.3%	66.7%	50.0%	65.7%

ASSESSORS PARCEL BOOK NO. 77 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	22	22	2	18	64
ODOR	22	15	1	20	58
COLOR	29	23	2	7	61
OTHER	8	18	2	2	30
NONE	31	9	2	10	52
TASTE, ODOR OR COLOR	44	33	3	21	101
TASTE, ODOR, COLOR OR OTHER	48	42	5	21	116
NUMBER OF WELLS IN SURVEY	79	51	7	31	168
% WELLS WITH T,O,C QUALITY PROBLEM	55.7%	64.7%	42.9%	67.7%	60.1%
% WELLS WITH T,O,C,X QUALITY PROBLEM	60.8%	82.4%	71.4%	67.7%	69.0%

ASSESSORS PARCEL BOOK NO. 78 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	4	8	0	2	14
ODOR	2	8	0	2	12
COLOR	6	16	1	5	28
OTHER	3	1	1	3	8
NONE	6	18	0	4	28
TASTE, ODOR OR COLOR	9	17	1	5	32
TASTE, ODOR, COLOR OR OTHER	12	18	1	7	38
NUMBER OF WELLS IN SURVEY	18	36	1	11	66
% WELLS WITH T,O,C QUALITY PROBLEM	50.0%	47.2%	100.0%	45.5%	48.5%
% WELLS WITH T,O,C,X QUALITY PROBLEM	66.7%	50.0%	100.0%	63.6%	57.6%

ASSESSORS PARCEL BOOK NO. 84 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	14	10	0	5	29
ODOR	14	6	0	4	24
COLOR	20	13	0	6	39
OTHER	7	2	0	3	12
NONE	11	8	0	8	27
TASTE, ODOR OR COLOR	23	15	0	6	44
TASTE, ODOR, COLOR OR OTHER	27	16	0	7	50
NUMBER OF WELLS IN SURVEY	38	24	0	15	77
% WELLS WITH T,O,C QUALITY PROBLEM	60.5%	62.5%	N/A	40.0%	57.1%
% WELLS WITH T,O,C,X QUALITY PROBLEM	71.1%	66.7%	N/A	46.7%	64.9%

ASSESSORS PARCEL BOOK NO. 104 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	14	7	0	3	24
ODOR	13	8	0	3	24
COLOR	23	8	0	5	36
OTHER	13	1	0	0	14
NONE	40	4	0	4	48
TASTE, ODOR OR COLOR	29	11	0	6	46
TASTE, ODOR, COLOR OR OTHER	39	11	0	6	56
NUMBER OF WELLS IN SURVEY	79	15	0	10	104
% WELLS WITH T,O,C QUALITY PROBLEM	36.7%	73.3%	N/A	60.0%	44.2%
% WELLS WITH T,O,C,X QUALITY PROBLEM	49.4%	73.3%	N/A	60.0%	53.8%

ASSESSORS PARCEL BOOK NO. 113 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	7	11	0	3	21
ODOR	7	10	0	3	20
COLOR	12	26	1	8	47
OTHER	8	15	0	4	27
NONE	35	46	2	15	98
TASTE, ODOR OR COLOR	14	31	1	9	55
TASTE, ODOR, COLOR OR OTHER	22	42	1	12	77
NUMBER OF WELLS IN SURVEY	57	88	3	27	175
% WELLS WITH T,O,C QUALITY PROBLEM	24.6%	35.2%	33.3%	33.3%	31.4%
% WELLS WITH T,O,C,X QUALITY PROBLEM	38.6%	47.7%	33.3%	44.4%	44.0%

ASSESSORS PARCEL BOOK NO. 130 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	29	20	1	17	67
ODOR	27	24	0	17	68
COLOR	32	37	1	20	90
OTHER	21	20	1	6	48
NONE	88	28	4	33	153
TASTE, ODOR OR COLOR	51	47	1	27	126
TASTE, ODOR, COLOR OR OTHER	64	57	2	30	153
NUMBER OF WELLS IN SURVEY	152	95	6	63	306
% WELLS WITH T,O,C QUALITY PROBLEM	33.6%	55.3%	16.7%	42.9%	41.2%
% WELLS WITH T,O,C,X QUALITY PROBLEM	42.1%	67.1%	33.3%	47.6%	50.0%

ASSESSORS PARCEL BOOK NO. 134 QUALITY PROBLEM	NUMBER OF RESPONSES WITH INDICATED QUALITY PROBLEM SHALLOW WELLS 0-150 FT	INTERMEDIATE WELLS 151-350 FT	DEEP WELLS > 350 FT	WELLS WITH DEPTH UNKNOWN	SUMMARY ALL WELLS
TASTE	6	2	0	3	11
ODOR	4	1	0	2	7
COLOR	5	1	0	2	8
OTHER	2	0	0	3	5
NONE	18	1	0	6	25
TASTE, ODOR OR COLOR	8	3	0	4	15
TASTE, ODOR, COLOR OR OTHER	10	3	0	7	20
NUMBER OF WELLS IN SURVEY	28	4	0	13	45
% WELLS WITH T,O,C QUALITY PROBLEM	28.6%	75.0%	N/A	30.8%	33.3%
% WELLS WITH T,O,C,X QUALITY PROBLEM	35.7%	75.0%	N/A	53.8%	44.4%

CHAPTER 7. MATHEMATICAL MODEL

One objective of the Santa Rosa Plain Study was to develop a mathematical simulation model of the underlying ground water reservoir for subsequent use in exploring alternative ground water management programs for this portion of Sonoma County. The simulation model was compiled on a computer program developed by the Department of Water Resources in 1970. This program has been employed in several ground water basins in Northern California, the most recent being Livermore Valley.

The computer simulation of the ground water system is accomplished by dividing the ground water reservoir into a series of nodes or cells wherein the hydraulic head within each cell is implicitly contained within the hydrologic equation representing head at the nodal point, temporal change in storage within each cell, and the elements of ground water flow into and out of each cell.

To apply this approach, a nodal network (shown on Figure 18) is superimposed on the ground water reservoir. The center of each element -- or cell -- of this network is called a node and has an identifying number. The ground water model is based on the assumption that all physical and hydrologic characteristics of a particular cell are located at the node point. Ground water flow between adjacent cells is governed by Darcy's law and thus is proportional to the hydraulic gradient, and the cross-sectional area and permeability of the aquifer at the interface of the adjacent cells.

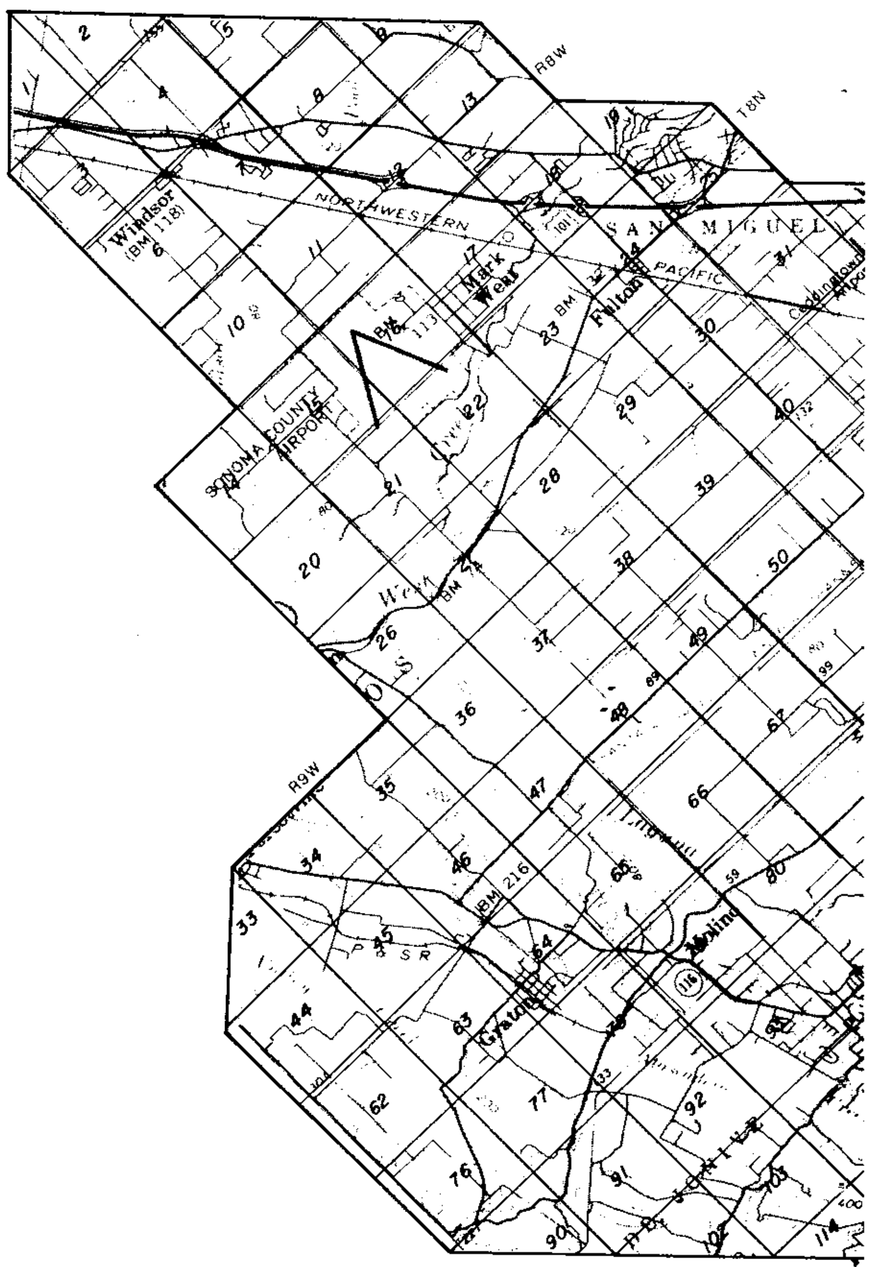
The mass balance equation written for each cell in the model results in a system of simultaneous equations with the hydraulic head as the only unknown. This system of equations is solved for each time step of the entire hydrologic period being evaluated by an iterative procedure, which is repeated until it has converged to the solution.

Description of the Model

The ground water model for the Santa Rosa Plain is based on one-mile-square cells covering the Santa Rosa Plain. Each cell is identical to a section of land as defined by U. S. Public Lands surveys or, in the absence thereof, by projections into the unsurveyed area. The node point is the center of the section. Exceptions to this are a number of triangular cells on the boundary of the model. These cells are half a section bisected across the diagonal. The ground water model has 193 cells composed of 167 full sections and 26 diagonal half sections.

The entire boundary of the model network, with two exceptions, has been assumed to be a no-flow boundary. The exceptions are where Santa Rosa Creek and an unnamed creek enter the model area on the eastern side of cell 59 and where Matanzas Creek enters the model area on the southern side of cell 89. There may be other boundary segments across which some ground water may move; however, any such quantity of flow is considered minor and is not included by the model. Such possibilities might be outflow at Mark West Creek (cell 20), outflow at Green Valley Creek (cell 33), and outflow at Petaluma River (cell 190).

Data input to the model describes the physical conditions affecting ground water within the various cells of the ground water basin. Nodal parameters indicate for each cell its surface area, ground surface and bedrock elevations, and average specific yield values. Connections between nodes are made by numbered branches, each of which has its

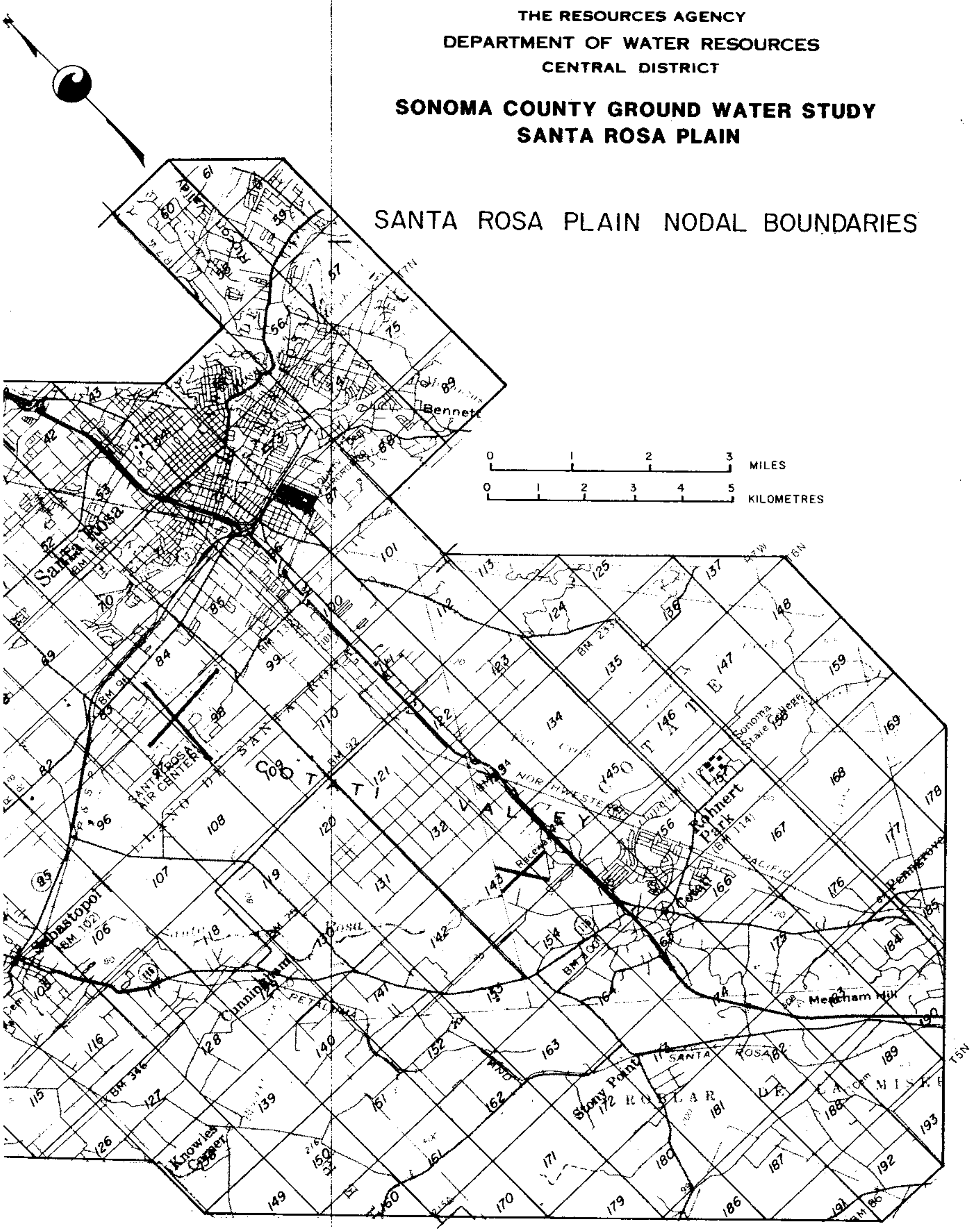


Windsor
(BM 118)
NORTHWESTERN
PACIFIC
SAN MIGUEL
Mark West
Fulton
SONOMA COUNTY AIRPORT
R8W
T8N
R9W
Graton

FIGURE 18

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT

SONOMA COUNTY GROUND WATER STUDY
SANTA ROSA PLAIN



own characteristics, such as width, length, the elevation below which transmissivity is assumed to be zero, and estimated transmissivity.

Faults and lateral variations in thickness and permeability of aquifer materials restrict horizontal movement of ground water. To represent this impaired horizontal movement of ground water flow across these restrictions mathematically, the transmissivities of the branches and connections between certain nodes were set to zero. The impairments so represented are the Sebastopol fault, which bisects the Santa Rosa Plain on a northwest to southeast line from about Vine Hill to Penngrove, and the topographical restrictions on the west side of cells 56 and 88, on the west and south sides of cells 113, 125, and 137, and on the north and west sides of cells 178 and 185.

Hydrologic Inventory

An inventory of recharge to and withdrawals from a ground water basin over a given base period provides information on the relative importance of various water sources and uses. Annual inventories record the effect of changing land and water use on the ground water reservoir. When the results of an annual inventory agree with historical water level changes, the values used to develop the inventory are considered verified.

The 15-year period from 1960-61 through 1974-75 was selected as the study period for the Santa Rosa Plain ground water basin, as shown in Figure 19, because it contains a mixture of wet and dry years approximating long-term climatic conditions. For the study period, data are available to calculate the items of the hydrologic inventory, either directly or indirectly. Ideally, the study period should be preceded by and end with periods of lower than normal wetness to allow drainage of the water in transit through the unsaturated zone above the main ground water body. Such an ideal case was not used for this model.

Because the ground water body in the Santa Rosa Plain is essentially full, and in view of the uncertain nature of the data that provided all of the remaining components of the hydrologic equation, it was assumed that differences resulting from a lack of before-and-after dry years would be minor. Any refinements of this initial modeling effort, however, should include such dry years.

To evaluate how a ground water basin stores and transmits water requires knowledge of water use, geology, hydrology, and water quality. During any given period of time, for any hydrologic system, the amount of water therein must be accounted for by the net change in storage, total inflow, and total outflow. This relationship is consistent with the mass balance principles of physics, and is expressed by the hydrologic equation:

INFLOW - OUTFLOW = CHANGE IN STORAGE

For the portion of the hydrologic system relating directly to ground water, the terms are as follows:

INFLOW = Recharge from rain and recharge from applied water and recharge from streams and artificial recharge and subsurface inflow.

OUTFLOW = pumpage and evapotranspiration by phreatophytes and rising water and subsurface outflow.

CHANGE IN STORAGE = change in amount of ground water in storage.

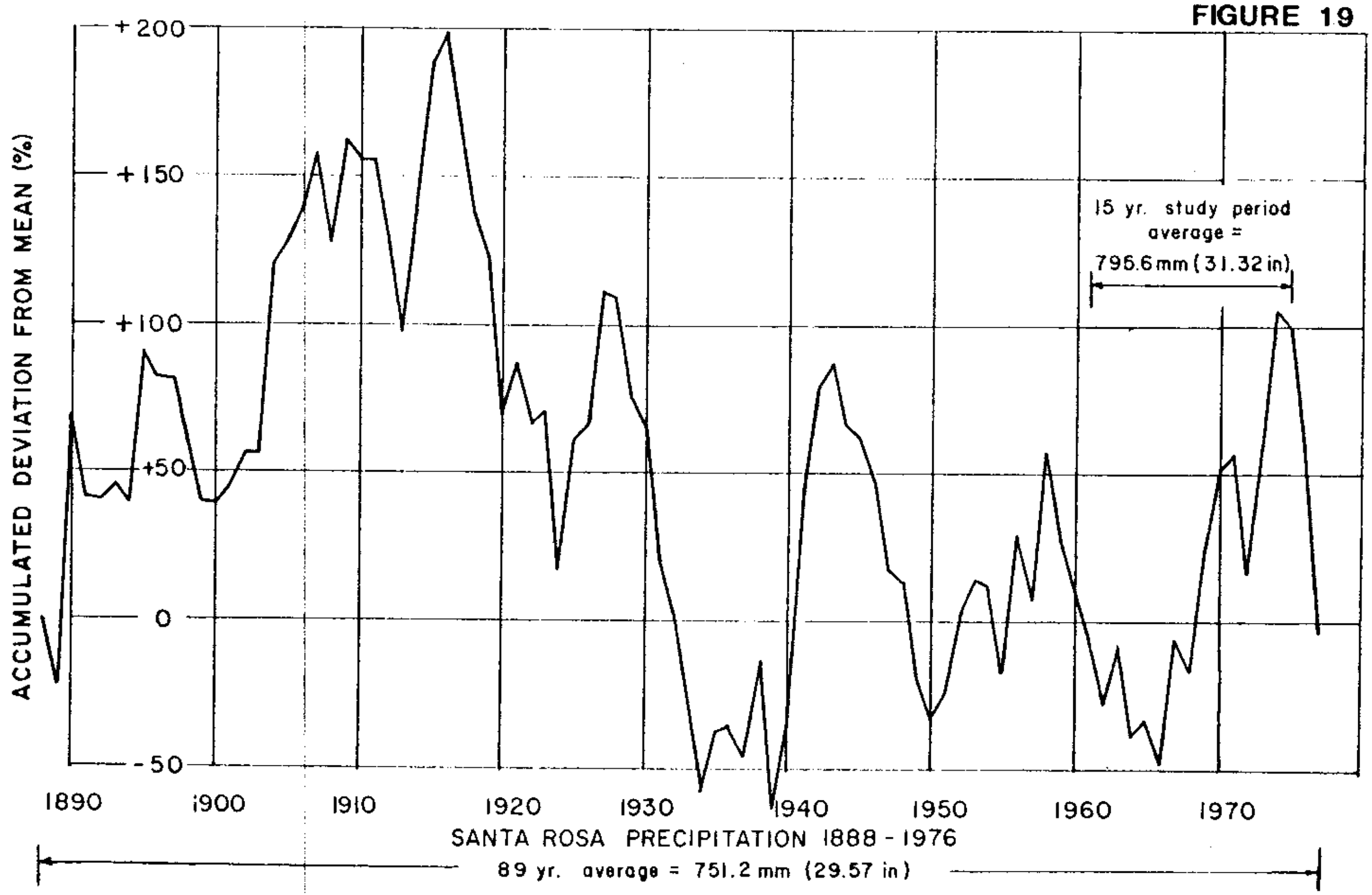
Figure 20 summarizes the many elements in such a hydrologic system. Each of the inflow and outflow items in the hydrologic equation study is determined annually over the study period and tested by comparing the net amounts to the change in ground water storage. The annual amounts of recharge, withdrawal, and change in storage have been estimated for each nodal area in the model. In this chapter the results have been summarized for the total ground water area. Detailed nodal information is available in department files.

Some of the items in the ground water inventory are directly measurable, some must be calculated, and some were measured for only a part of the study period and were calculated for the remainder.

Of the items calculated, most were on a water year basis (October 1 through September 30). The principal exception is ground water pumpage, which was calculated on a calendar year basis. Because each calendar year and water year contain the same summer period, and since most pumpage occurs in this period, use of differently defined years has a minor effect.

The ground water inventory results in mathematical balance or accounting of all the water resources in the basin, including changes in the amounts of water in

FIGURE 19



RELATIONSHIP OF ANNUAL PRECIPITATION TO MEAN PRECIPITATION storage both underground and in surface reservoirs. The accuracy of the balance analysis can be gaged by how close the change in ground water storage, as calculated from changes of observed historical water levels, compares with the difference between calculated recharge to and withdrawals from the ground water system.

The inventory is based on two items: the first treats the basin as a whole; the second subdivides the ground water area into many small units and uses. These units in the mathematical model were prepared to simulate the hydrologic system of the study area and to provide a means for testing the reactions of the ground water system to alternative plans.

Recommendations

Completion of the geohydrology phase of the study and development of a verified mathematical model of the Santa Rosa Plain will provide an opportunity to evaluate the effects of future actions relating to water resources. Additional studies should be made to:

° Reevaluate the historical water levels on the basis of the water level monitoring network recommended in 1980.

° Determine what portion of the area's future water demands can be met by ground water when used conjunctively with surface, imported, and reclaimed water sources in a variety of alternative operational plans.

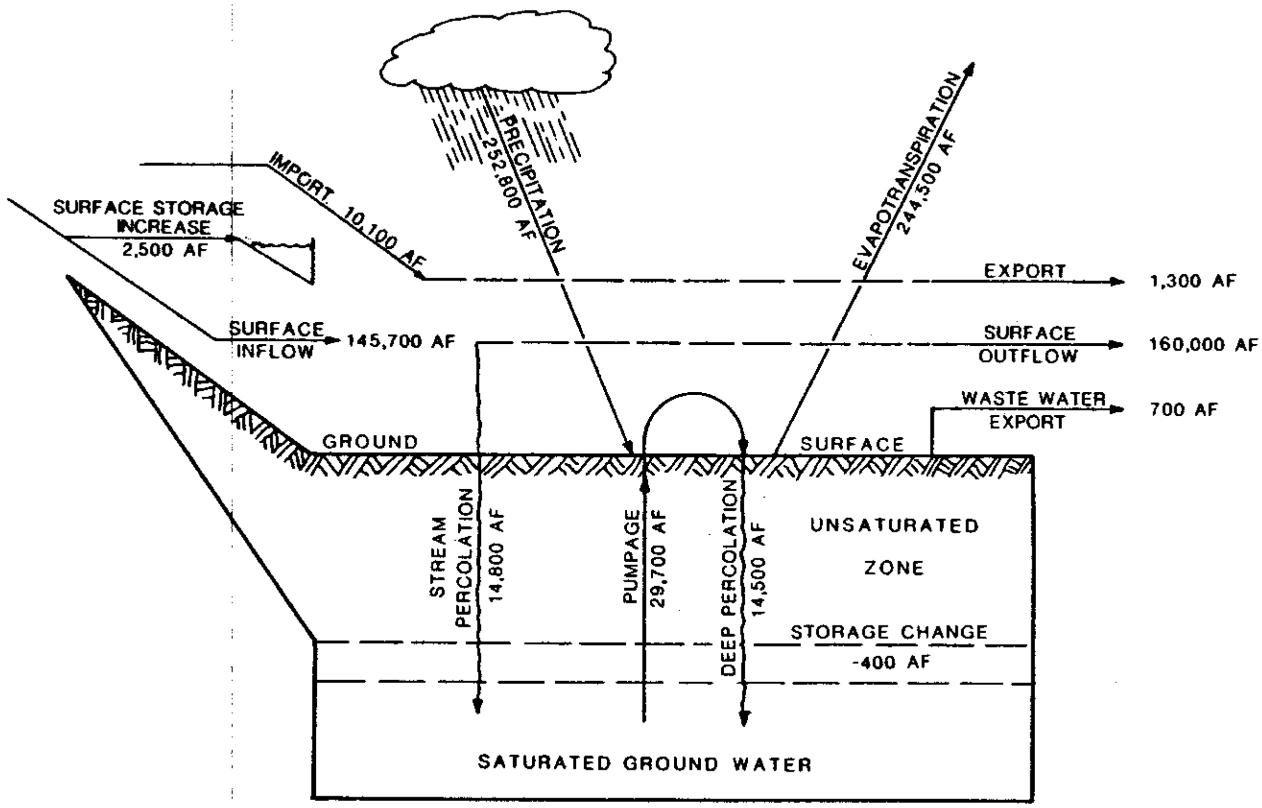
° Determine the effects of possible combinations of pumping and recharge modifications on the movement or containment of areas of poor water quality.

Three steps can be taken to improve verification of the mathematical model. One would be to adjust the nodal storage factors and the transmissivities between nodes so the computed water levels will more closely match the historical water levels. These adjustments need to be done until the best agreement between the computed and historical water levels is obtained.

A second step would be to adjust the net recharge for each node within the level of accuracy of data. The total net recharge for all the nodes should remain the same, but increments need to be shifted from one node to another.

A third step would be to reevaluate the validity of historical water levels in nodes where historical and computed water levels do not match. Figure 21 is a plot of the original model run showing the computed and historical water levels for nodes 17, 60, and 157. These nodes are examples of large agricultural pumping for node 17, a typical node with unknown boundary conditions for node 60, and large municipal pumping for node 157. These nodes and most other nodes in the study are generally within acceptable limits and should be made much better with further calibration.

HYDROLOGIC BALANCE
(15-YEAR AVERAGE, 1961 - 1975)



SCHEMATIC REPRESENTATION

	ANNUAL QUANTITIES (ACRE-FEET)	(dam^3)
SUPPLY ITEMS		
(MEASURED AT GROUND SURFACE)		
PRECIPITATION	252,800	311 800
SURFACE STREAMFLOW	145,700	179 700
IMPORTS	10,100	12 500
GROUND WATER PUMPAGE	29,700	36 600
TOTAL SUPPLIES	438,300	540 600
DISPOSAL ITEMS		
(MEASURED AT GROUND SURFACE)		
SURFACE OUTFLOW	160,000	197 400
EVAPOTRANSPIRATION	244,500	301 500
EXPORTS	1,300	1 600
WASTE WATER EXPORT	700	900
SURFACE RESERVOIR STORAGE INCREASE	2,500	3 100
PERCOLATION TO GROUNDWATER		
a.) FROM STREAMS	14,800	18 200
b.) FROM LAND AREAS	14,500	17 900
TOTAL DISPOSAL	438,300	540 600

FIGURE 20

The specific yield of some clays and sandy clays in Santa Rosa Plain is so low that wells in those sediments are not capable of producing large quantities of ground water. The western uplands underlain by the Merced Formation generally are capable of substantial ground water development, because recharge is adequate.

Greater cyclical use of ground water stored in those areas in the Santa Rosa basin where recharge is now rejected could be realized if ground water levels were drawn down further, making more storage space available. The additional ground water storage space could be recharged in wet periods, allowing extraction during subsequent dry periods, if there are nearby natural or artificial recharge areas that could supply additional recharge water. Those areas removed either by distance or geologic conditions from areas of natural or artificial recharge will take much longer to recover from increased pumpage. The distance between areas of ground water use and areas of ground water recharge may be a major factor in the way the Santa Rosa Plain ground water basin can be operated.

A management plan should also include evaluation of some techniques for increasing recharge in the Rohnert Park area. Because geologic constraints may impede the flow of recharging ground water into the cone of depression beneath Rohnert Park or other areas in southern Santa Rosa Plain, some kind of artificial recharge program in conjunction with managed water withdrawals may be desirable. A reduction in ground water pumpage would also allow the ground water levels in that area to recover.

CHAPTER 9. PROPOSED GROUND WATER DATA COLLECTION PROGRAMS

Additional data on ground water are needed to complete calibration and verification of the computer model so it can be used as a predictive tool to refine estimates of the total water in storage and to define more precisely the hydrology of the Santa Rosa Plain ground water basin so that the ground water resources can be managed prudently.

Determination of Ground Water Levels

To accurately evaluate the ground water potential of an area, a wide areal distribution of ground water level data gathered over a long period of time is necessary. This information can be used to determine the overall condition of the basin and to define areas of intense, increasing, or decreasing ground water pumpage. Ground water level data can also be used to evaluate the effects of geologic structures, such as faults and geologic formations, on the movement and occurrence of ground water. Ground water level maps constructed from these data permit a more accurate estimate of total ground water in storage.

Until 1980, 87 wells in the Santa Rosa Plain study area were monitored by Sonoma County Water Agency and the Department of Water Resources. A new network is being implemented consisting of 52 of the presently monitored wells and existing wells at 60 additional locations (Figure 22). The 60 additional locations were selected on the basis of geology, hydrology, existence of a well at that location, and information on the construction of the well. Construction data are available for the additional wells; these data are vital because they indicate the zone from which ground water is being extracted. Previously monitored wells lacking these data will be dropped from the new network.

Wells at the additional locations tap a single aquifer or zone, and therefore represent the water level of this ground water body alone. A few "deep composite" wells have been selected for areas where no other wells are available; construction data are available for these wells, which tap ground water from several aquifers or zones. Water levels in deep composite wells can be correlated with water levels in other wells of similar depth and construction (gravel packed or multiple perforations) to determine the effects of faults and other barriers on the movement of ground water.

After several years of measurement, data from the new network should be analyzed to better define ground water reservoir hydrology, including the role of faults in ground water movement and the extent of aquifer continuity. After sufficient ground water level data have been collected to verify estimates of total ground water in storage, the monitoring network should be reevaluated. Wells from which data are no longer necessary should be dropped, and other wells should be added where data are insufficient.

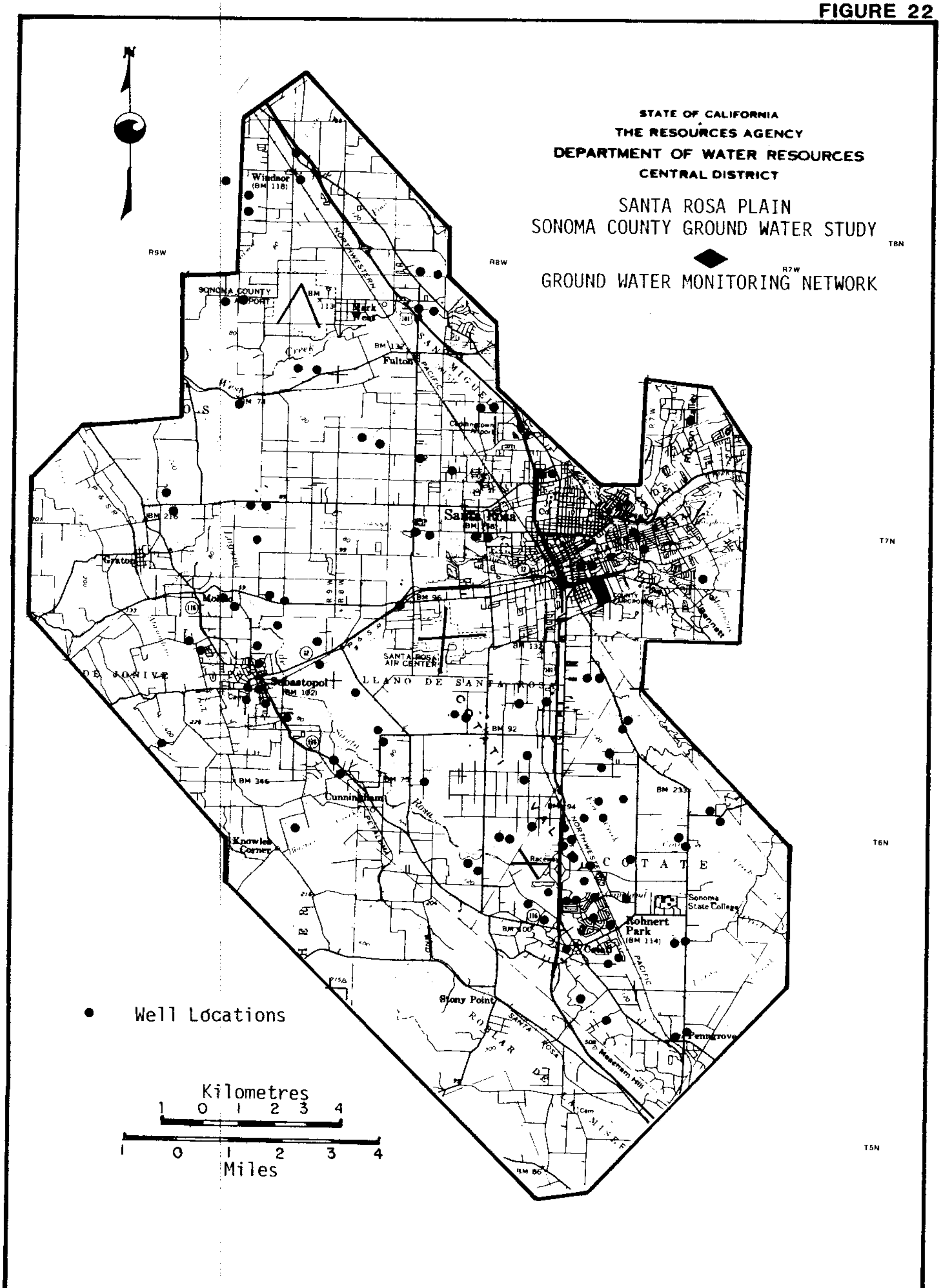
Determination of Streamflow

Among the data required to develop and verify a computer model of a ground water reservoir are long-term records for streams flowing into and out of the model area. During initial development of a model, these records help determine the amount of ground and surface water moving into and out of each subarea or "cell" within the model. After a model is completed, subsequent records enable verification of the model by comparison of the predicted and actual behavior of water in each cell.

The proposed stream monitoring network in the Santa Rosa Plain consists of four permanent and two temporary recording gages, and two observation points. Permanent gaging stations should be located on Blucher, Mark West, Santa Rosa, and Copeland creeks. Temporary gaging stations should be located on Mark West and Green Valley creeks. Observation points should be located on Windsor and Pool creeks. At three other locations immediately downstream from Matanzas and Santa Rosa Creek reservoirs and Spring Creek diversion dam, observation points should be installed if reservoir release records are not available. These 11 station locations were developed from a network of stream gaging stations and observation points within the Santa Rosa Plain model area that was measured by Sonoma County Water Agency during the drought in 1976 and 1977.

The station locations for the proposed network were chosen after considering the diverse hydrologic factors that influence runoff from the slopes of the northwest-southeast trending valleys. These factors include the land surface gradient, extent of forestation, and direction of developing storm systems. The network will help determine the amount of surface water lost due to infiltration to the ground water body from stream channels, diversion of streamflows for agricultural use, water use by phreatophytes, and evaporation. Better estimates of water returned to the system from applied water for agriculture from both ground and surface water sources will also be needed for model verification.

FIGURE 22


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
SANTA ROSA PLAIN
SONOMA COUNTY GROUND WATER STUDY
GROUND WATER MONITORING NETWORK
Well Locations
Kilometres
1 0 1 2 3 4
1 0 1 2 3 4
Miles
Windsor
Sonoma County Airport
Mark West
Fulton
Santa Rosa
Graton
Sebastopol
Santa Rosa Air Center
Llano de Santa Rosa
Cunningham
Knowles Corner
Cotati
Rohnert Park
Sonoma State College
Stony Point
Penngrove
R9W
R8W
R7W
T8N
T7N
T6N
T5N

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GLOSSARY

Agglomerate. A pyroclastic volcanic rock containing a predominance of rounded to subangular fragments greater than 32 mm in diameter.

Alluvial Fan Deposit. A cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream. The fans generally form where streams issue from mountains upon the lowlands.

Alluvium. A geologic term describing beds of sand, gravel, silt, and clay deposited by flowing water during comparatively recent geologic time.

Anion. A negatively charged ion, for example, OH^- or Cl^-.

Anticline. A fold, generally convex upward, whose core contains the older rocks.

Aquifer. A geologic formation that stores, transmits, and yields significant quantities of water to wells and springs.

Aquifer Continuity. Hydraulic interconnection between and within aquifers so that ground water stored in one aquifer or portion of an aquifer is able to move into another aquifer or into another portion of an aquifer.

Artesian. An adjective referring to ground water confined under hydrostatic pressure.

Brackish. Water that is intermediate in salt content between normal fresh water and normal sea water.

Breccia. A rock made up of highly angular, coarse, broken fragments.

Cation. A positively charged ion, for example, H^+ or Ca^{++}.

Chert. A hard, dense siliceous rock of sedimentary origin.

Clay. A term which denotes either (1) particles, regardless of mineral composition, with diameter less than 1/256 mm or (2) a sediment composed primarily of these particles.

Confined. Refers to ground water under sufficient pressure to rise above the aquifer containing it when the aquifer is penetrated by a well. The difference between the water level in a well and the top of the aquifer is the Hydrostatic Pressure. Confined ground water is also known as Artesian.

Conglomerate. A cemented rock containing rounded fragments corresponding in size to gravel. The consolidated equivalent of gravel.

Connate Water. Water entrapped in the openings between particles of a sedimentary rock at the time the rock was deposited. The water may be derived from either ocean water or land water.

Consolidated. Firm and coherent.

Constant-Rate Pump Test. Test pumping of a water well at a constant rate of discharge while the drop in the ground water level (drawdown) is recorded in the well or a nearby observation well. The drawdown is plotted versus time since pumping began to determine Transmissivity, the rate at which ground water will flow through a unit width of the aquifer.

Contamination. Contamination means an impairment of the quality of the waters of the State by waste to a degree which creates a hazard to the public health through poisoning or through the spread of disease. Contamination includes any equivalent effect resulting from the disposal of waste, whether or not waters of the State are affected.

Continental Deposits. Sedimentary deposits laid down within a general land area and deposited in lakes or streams or by the wind; nonmarine deposits.

Diatomite. An earthy deposit composed of nearly pure silica and consisting of the shells of microscopic plants called diatoms.

Dip. The angle at which a planar feature, such as a fault or formation bedding plane is inclined from the horizontal.

Evapotranspiration (ET). Loss of water from a land area through transpiration of plants and evaporation from the soil.

Fault. A fracture, or fracture zone, along which there has been displacement of the two sides relative to one another. This displacement may be a few centimetres or many kilometres. An Active Fault is one which has had surface displacement within Holocene time (about the last 11,000 years). The inverse of this, that other faults are inactive, is not necessarily true. A Potentially Active Fault is one which shows evidence of displacement during Quaternary time (last 2 to 3 million years).

Fault Plane. The more or less planar surface of a fault along which dislocation has taken place.

Fault Trace. The surface expression of a fault.

Fault Zone. An area along the trace of a large fault consisting of numerous interlacing small faults and/or a confused zone of gouge.

Fold. A bend in rock strata. An Anticline is an upward fold; it influences ground water by inducing flow away from the fold axis. A Syncline is a downward fold; it influences ground water by inducing flow toward the fold axis.

Formation. A geologic term that designates a specific group of underground beds or strata which have been deposited in sequence one above the other and during a specific period of geologic time.

Fresh Water. Water that is not so affected by sea water intrusion, nitrate pollution, or other water quality problem, as to be detrimental for human use or consumption.

Gouge. Finely abraded material occurring between the walls of a fault, the result of grinding movement.

Gravel. A term which denotes either (1) particles, regardless of mineral composition, with diameter greater than 2 mm or (2) unconsolidated sediment composed primarily of these particles. Gravel frequently is found as lens-shaped units within sandy deposits.

Greenstone. An altered basic igneous rock of greenish color due to the presence of such minerals as chlorite, hornblende, and epidote.

Ground Water Barrier. A body of material which is impermeable or has only low permeability and which occurs below the land surface in such a position that it impedes the horizontal movement of ground water and consequently causes a pronounced difference in the level of the water table on opposite sides of it.

Ground Water Basin. An area underlain by one or more permeable formations capable of furnishing a substantial supply of acceptable quality water. Usually, there is little movement of ground water from one basin to another.

Hydraulic Conductivity. The rate of flow of water in gallons per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temperature or adjusted for a temperature of 60°F.

Hydraulics. The aspect of engineering that deals with the flow of water or other liquids.

Hydrograph. A graph showing the changes in the water level in a well with respect to time.

Hydrology. The science that relates to the distribution and circulation of naturally occurring water on and under the earth's surface.

Igneous. Rock formed from the solidification of molten material, either at depth or on the ground surface.

Infiltration. The flow or movement of surface water downward through the soil to become ground water.

<u>Interbedded</u>. Occurring between beds, or lying in a bed parallel to other beds of a different material.

<u>Intrusive</u>. Igneous rock which cools and solidifies below the earth's surface.

<u>Limestone</u>. A sedimentary rock consisting chiefly of calcium carbonate.

<u>Marine Deposits</u>. Sedimentary deposits laid down on the floor of the ocean.

<u>Mathematical Model</u>. A computer technique which simulates responses of ground water to changes in recharge and pumping patterns. Used as a tool to predict future water levels.

<u>Metamorphic</u>. Rock which has been re-formed in the solid state in response to pronounced changes of temperature, pressure, and/or chemical environment and which takes place below the ground surface. A metamorphic rock originally was of a different form; i.e., it originally was igneous, sedimentary, or a different type of metamorphic rock.

<u>Methemoglobinemia</u>. A bluish or purplish discoloration (as of skin) due to deficient oxygenation of the blood which can be caused by excessive nitrates in drinking water.

<u>Milliequivalent</u>. A contraction of "milliequivalents per million", which is based on molecular weights; the units are "milligram equivalents per kilogram" if derived from data expressed in parts-per-million or "milligram equivalents per litre" if derived from data expressed in milligrams per litre. In analyses expressed in milliequivalents, unit concentrations of all ions are chemically equivalent.

<u>Oxidation</u>. The process of combining with oxygen; rust is a product of oxidation.

<u>Percolation Rate</u>. The rate at which water passes through the fine interstices in earth materials.

<u>Permeability</u>. The ability of a geologic material to transmit fluids such as water. The degree of permeability depends on the size and shape of the pore space and the extent, size, and shape of their interconnections.

<u>Pollution</u>. Pollution means an alteration of the quality of the waters of the State by waste to a degree which unreasonably affects (1) such waters for beneficial uses, or (2) facilities which serve such beneficial uses. Pollution may include contamination.

<u>Potable</u>. Suitable for drinking; said of water and beverages.

<u>Recharge</u>. The processes involved in the absorption and addition of water to the zone of saturation. In this report, <u>natural recharge</u> is recharge that occurs without assistance or enhancement by people; <u>artificial recharge</u> is recharge that occurs when people modify the physical system to increase recharge.

Reduction. The process of removing oxygen; the opposite of oxidation.

Saline. Consisting of or containing salts (minerals), the most common of which are potassium, sodium, or magnesium in combination with chloride, nitrate, or carbonate.

Sand. A term which denotes either (1) particles with diameter ranging from 1/16 to 2 mm or (2) a sediment composed primarily of these particles.

Scoria. Material ejected from a volcanic vent. Such material is usually vesicular, dark in color, heavy, and has a partly glassy-partly crystalline texture.

Sedimentary. Said of rocks formed from sediments. Includes such rock types as sandstone, conglomerate, shale, etc.

Serpentinite. A rock consisting almost entirely of the mineral serpentine, which is the alteration product of several types of ultrabasic rocks.

Silt. A term which denotes either (1) particles with diameter ranging from 1/256 to 1/16 mm or (2) a sediment composed primarily of these particles.

Soil. A natural body consisting of layers or horizons of mineral and/or organic constituents of variable thicknesses, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics.

Sorting. The degree of similarity, in respect to some particular characteristic (frequently size), of the component particles in a mass of material.

Specific Yield. The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity, to the volume of that mass. This ratio is expressed as a percentage.

Storage Capacity. The volume of space below the land surface that can be used to store ground water. Total Storage Capacity is the total volume of space that could be used to store ground water. Available Storage Capacity is that volume of the total storage capacity that does not presently contain ground water and is therefore available to store recharged water.

Stream Gaging. The process by which the streamflow can be determined by measurement of the water level and velocity in the stream.

Sustained Yield. The volume of ground water that can be extracted annually from a ground water basin without causing adverse effects.

Syncline. A fold in which the core contains the younger rocks; it is generally concave upward.

Thermal Water. Hot or warm water.

Total Dissolved Solids (TDS). The total quantity of minerals (salts) in solution in water, expressed in milligrams per litre.

TRANSCAP. A computer program which determines transmissivity and storage capacity using specific yield data from individual wells. Averaged specific yield data are converted to transmissivities using equations of a curve developed by the DWR investigation of the Livermore and Sunol Valleys (Ford and Hills, 1974). For specific yield values from 3 to 9, the curve is described by the equation:

$$\Delta T = \Delta D\ (10)^{x};$$

$$\text{where } x = \left[3.5319 - \frac{7.16288}{(SY) - 0.84} \right]$$

and for specific yield values greater than 9, by the equation:

$$\Delta T = \Delta D\ [100\ (SY) - 500]$$

Where ΔT = incremental transmissivity (gallons/day/ft);

ΔD = incremental depth (ft); and

(SY) = percent value for average specific yield for a given interval.

Transmissivity. The rate of flow of water through each vertical strip of aquifer of unit width having a height equal to the saturated thickness of the aquifer and under a unit hydraulic gradient.

Tuff. A rock composed of compacted volcanic fragments smaller than 4 mm in diameter.

Unconformity. A surface of erosion that separates younger strata from older rocks; represents a substantial break or gap in the geologic record.

Water Table. (1) The upper surface of a zone of saturation except where that surface is formed by an impermeable body; (2) The surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere; (3) colloquially, the surface where ground water is encountered in a well in an unconfined aquifer.

Well Log. A record made by the driller of a water well which lists geologic materials encountered during drilling and information on the construction of the well such as casing perforations and sanitary seal.

Zone of Saturation. A subsurface zone in which all the interstices are filled with water under pressure greater than that of the atmosphere.

Definitions Modified from the Following Sources:

American Geological Institute, 1976, "Dictionary of Geological Terms". Revised Edition.

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Ford, R. S., 1975, "Evaluation of Ground Water Resources: Sonoma County", California Department of Water Resources. Bulletin 118-4, Volume 1: "Geologic and Hydrologic Data".

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GEOLOGY COMPILED FROM THE FOLLOWING SOURCES:

Blake, M. C., et al, 1971, "Preliminary Geologic Map of Western Sonoma County and Northernmost Marin County". San Francisco Bay Region Environment and Resources Planning Study: U. S. Geological Survey. Basic Data Contribution 12.

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Fox, K. F., et al, 1973, "Preliminary Geologic Map of Eastern Sonoma County and Western Napa County". San Francisco Bay Region Environment and Resources Planning Study: U. S. Geological Survey. Basic Data Contribution 56.

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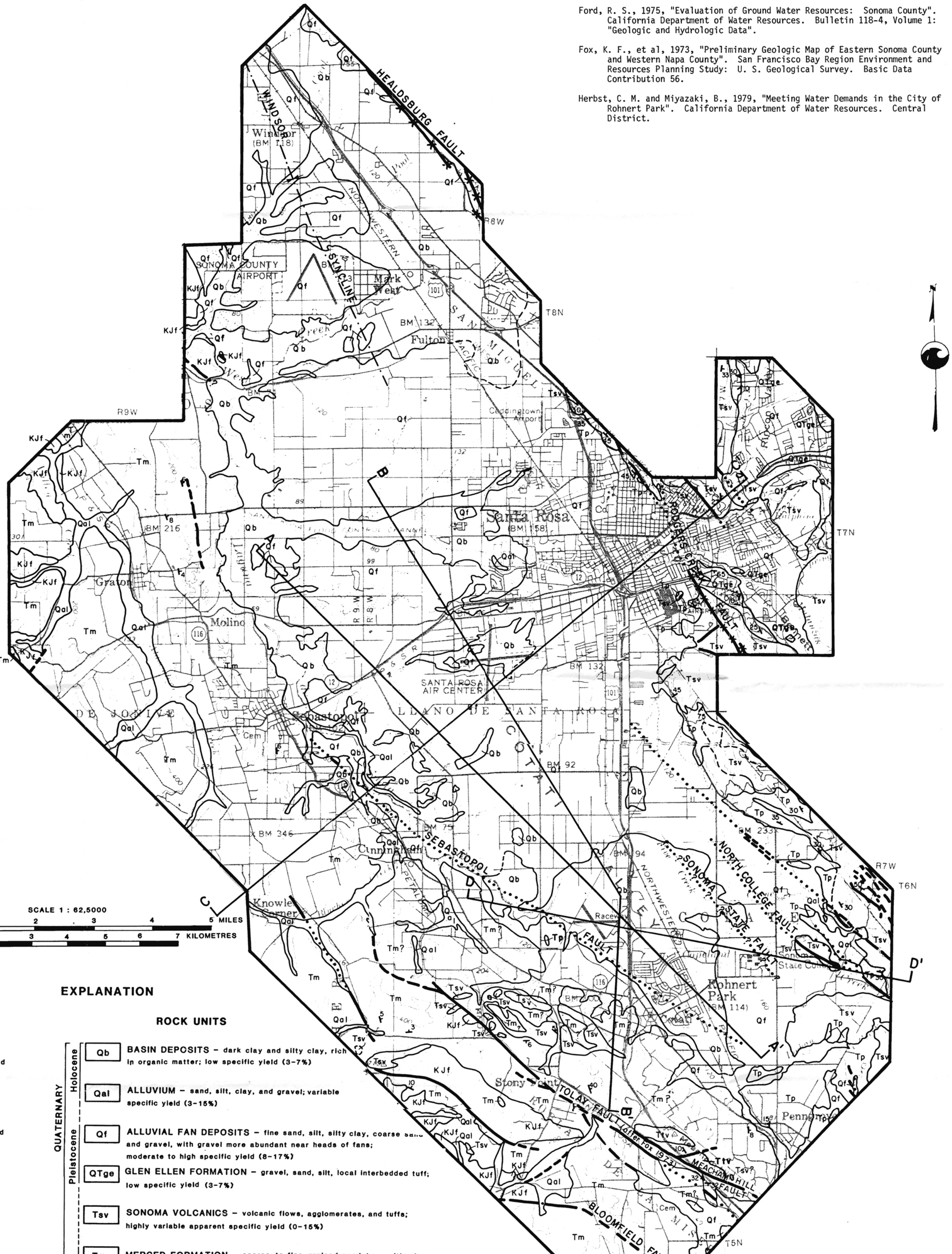

EXPLANATION

SYMBOLS

GEOLOGIC CONTACT
dashed where approximately located
dotted where concealed

FAULT
dashed where approximately located
dotted where concealed
arrow indicates direction of dip

x : indicates potentially active
? : questionable

SYNCLINE
showing approximate trace of axial surface and arrow indicates direction of plunge

STRIKE AND DIP of bedding

LOCATION OF GEOLOGIC SECTION

ROCK UNITS

QUATERNARY	Holocene	Qb	BASIN DEPOSITS – dark clay and silty clay, rich in organic matter; low specific yield (3-7%)
		Qal	ALLUVIUM – sand, silt, clay, and gravel; variable specific yield (3-15%)
	Pleistocene	Qf	ALLUVIAL FAN DEPOSITS – fine sand, silt, silty clay, coarse sand and gravel, with gravel more abundant near heads of fans; moderate to high specific yield (8-17%)
		QTge	GLEN ELLEN FORMATION – gravel, sand, silt, local interbedded tuff; low specific yield (3-7%)
TERTIARY	Pliocene	Tsv	SONOMA VOLCANICS – volcanic flows, agglomerates, and tuffs; highly variable apparent specific yield (0-15%)
		Tm	MERCED FORMATION – coarse-to fine-grained sandstone with minor amounts of clay; high specific yield (10-20%)
		Tp	PETALUMA FORMATION – clay and shale with minor amounts of sandstone; low specific yield (3-7%)
		Ttv	TOLAY VOLCANICS – volcanic flows, tuffs, breccias, and agglomerates; variable apparent specific yield (0-10%)
JURA-CRETACEOUS		KJf	FRANCISCAN COMPLEX – sandstone, shale, greenstone, chert, and serpentinite; very low specific yield (<3%)

GEOLOGY OF SANTA ROSA PLAIN
SONOMA COUNTY GROUND WATER STUDY